HYDRODYNAMIC MODELING
OF FLOODPLAIN GRADING ALTERNATIVES
ON THE LOS ANGELES RIVER AT TAYLOR YARD

Prepared for

Everest International Consultants, Inc.

Prepared by

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June 19, 2002

PWA Ref. #1491

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1. INTRODUCTION

The Los Angeles River drains 824 square miles (1230 square kilometers) and has a main channel approximately 50 miles (80 kilometers) long (Figure 1). Taylor Yard is a railroad routing and maintenance center located along the bank of the Los Angeles River, about 26 miles (42 kilometers) from the river's mouth at Long Beach. It is surrounded by residential and commercial development. The California State Coastal Conservancy (CSCC) is conducting a multiple objective feasibility study for Taylor Yard. Approximately 61 acres (24 hectares) are available for use as a floodplain. To help the CSCC evaluate the feasibility of restoration, a team of consultants led by Everest International Consultants, Inc. (EIC) has been formed. As part of this team, Philip Williams & Associates, Ltd. (PWA) has developed a one-dimensional hydrodynamic model to study the effects of conceptual grading alternatives on floodplain storage. This report presents the results of the modeling effort. The following alternatives were among those evaluated for 100-year, 50-year, 10-year, and 5-year flood events:

Alternative 1A	Excavation of 970 thousand cubic yards (TCY) from Taylor Yard, the 'A' indicates inclusion of Parcel D
Alternative 2	Excavation of 620 TCY from Taylor Yard
Alternative 4	Excavation of 890 TCY from river channel

Alternative 3 was dropped from consideration for the purposes of this analysis when it was determined that the elevation of Taylor Yard under this grading plan would be too high to permit overbank flows during a 100-year flood event. In addition to Alternatives 1A, 2 and 4, this study also evaluated the cumulative effect of implementing Alternative 1A at nine additional locations downstream from Taylor Yard. This hypothetical case, representative of a large-scale implementation of this type of flood management strategy, is referred to as Alternative X10.

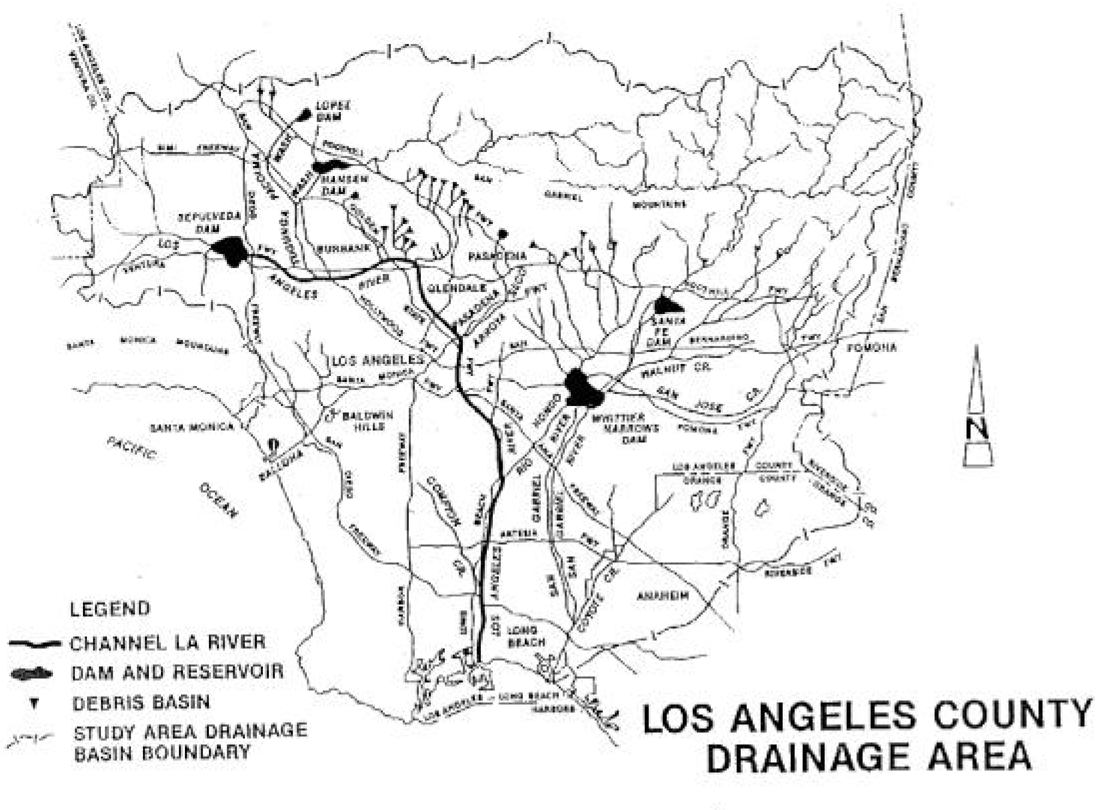


Figure 1-1. Drainage Area of Los Angeles River

2. MODEL PREPARATION

2.1 MODEL OVERVIEW

PWA used the hydrodynamic module of MIKE 11 to evaluate the effect of grading alternatives on flood discharge and water level. MIKE11 is a one-dimensional model that solves the vertically integrated mass and momentum conservation equations (Saint-Venant equations). Additional information about the model is provided in Appendix A.

Two models were developed – a larger-scale global model to estimate reduction in flood flows in the lower reaches of the river, and a higher-resolution local model to compare the proposed alternatives during the different flood events. The global model includes the main branch of the Los Angeles River from Tujunga Wash to Long Beach. The local model includes only the reach adjacent to Taylor Yard.

2.2 CHANNEL CROSS SECTIONS

Cross-sectional data were developed from CAD drawings provided by EIC, COE technical staff (COE 1997), the Los Angeles River Operation and Maintenance Manual (COE 1973), and a study by Robert Bein, William Frost and Associates (RBF 1993). The reference stationing used by the COE to identify channel reach locations is different from stationing used in the MIKE 11 model.

2.3 BOUNDARY CONDITIONS

For the global model, there are ten discharge boundaries and one water-level boundary within the MIKE11 model domain created to represent the system. The upstream boundary is an approximation of the discharge in the Los Angeles River below Tujunga Wash. The other nine discharge boundaries are lateral inflows along the entire reach. The downstream boundary is the predicted tidal elevations at Long Beach. COE technical staff and RBF (1993) provided 100-year flow data. Tidal data were obtained using the software *Tides & Currents*. Figure 2-1 identifies the global model extent and boundary condition locations. Figure 2-2 graphically shows the discharges for each boundary location.

For the local model, 50-year, 10-year, and 5-year discharges at Taylor Yard were used. They were obtained from RBF (1993).

Figure 2-1. Global Model Boundaries

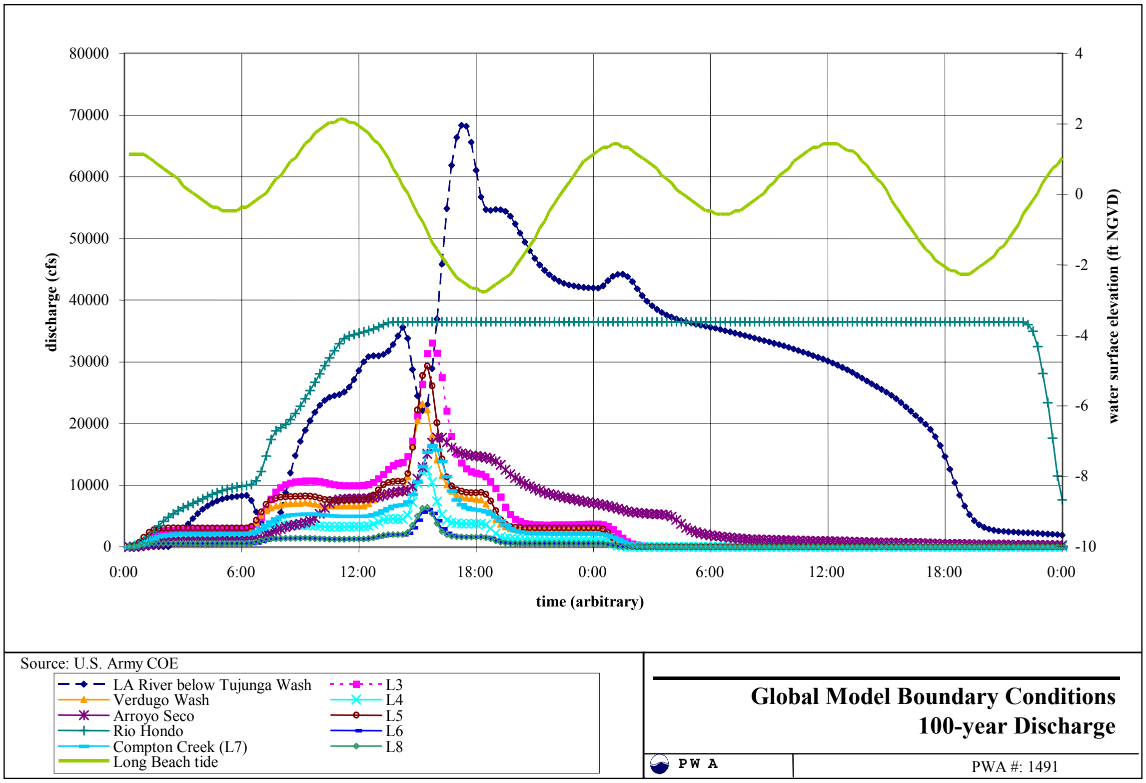


Figure 2-2. Global Boundary Conditions – 100-year Discharge

2.4 BRIDGES

There are several bridges immediately downstream from Taylor Yard that impact flow within the reach. To approximate the effect of these bridges, the Honma weir formula was used. Estimation of the weir coefficients is discussed below in Section 2.5.

2.5 DATA FITTING

To ensure that the results were comparable to previous studies, predicted water levels adjacent to Taylor Yard for a 100-year flood and existing channel conditions were fit to a similar case modeled by RBF using HEC-2 (RBF 1993). Adjustments were first made to the coefficients of the weirs (used to model three bridges downstream of Taylor Yard) until the water levels approximately matched. Channel roughness values were then slightly altered until the fit was adequate. The coefficients for the weirs were 0.46, 0.51, and 0.51. Channel roughness values used ranged from 0.016 just upstream from the site to 0.031 at Taylor Yard where the channel becomes overgrown with vegetation and covered in large cobbles and boulders. Comparison between HEC-2 and MIKE11 water surface profiles is presented in Figure 2-3.

It should be noted that the channel conditions assumed for modeling calibration may be significantly different than today's conditions. In particular, vegetation growth in mid-channel is likely to have a marked effect on channel roughness. If these conditions persist, their effects are likely to include local lowering of the Froude number and an increase in flow complexity across the channel. A range of potential roughness conditions would need to be assessed to help analyze the influence of potential roughness conditions on the design of alternatives before a decision is made on the preferred alternative. Hypothetically, potential restoration concepts for the Los Angeles River at Taylor Yard might involve roughness values of about 0.06 for a fully vegetated channel and about 0.04-0.06 for a restored and vegetated floodplain area. In-channel vegetation conditions are dynamic and may provide different roughness conditions as vegetation types, canopy coverage, and plant densities change over time. A vegetation maintenance program could potentially assist preserving certain vegetative types and roughness conditions in the channel. On the floodplain, local topographic conditions (in addition to vegetation) are very important in determining hydraulic roughness.

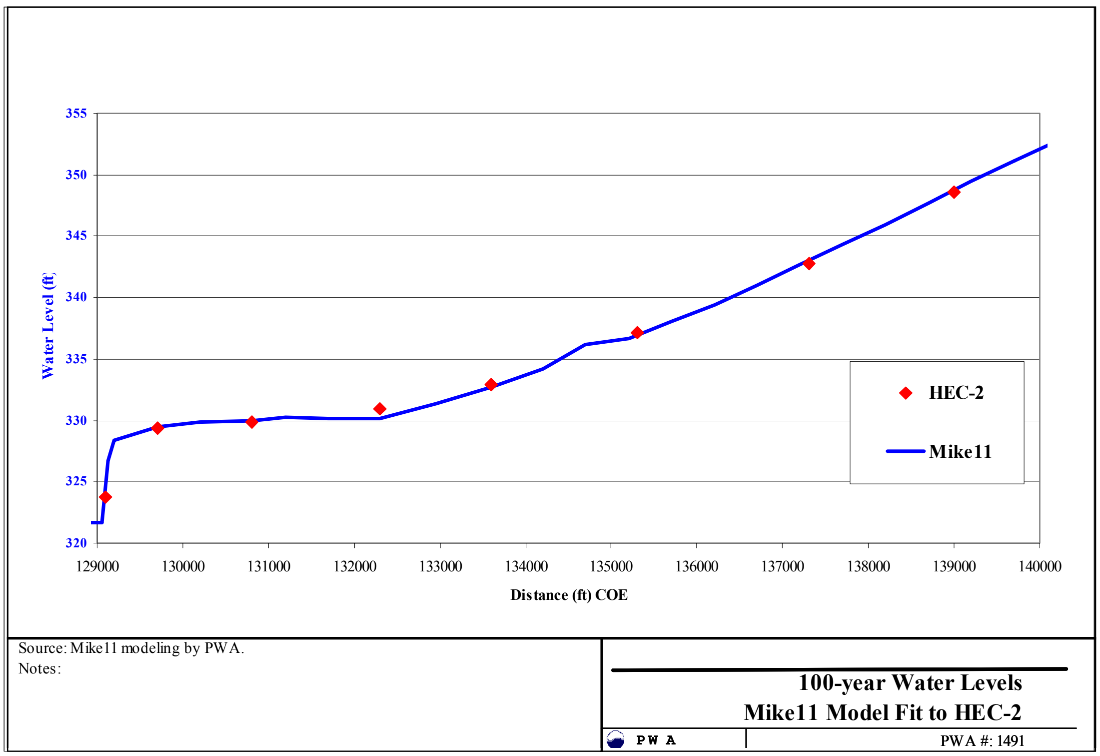


Figure 2-3. MIKE 11 model fit to HEC-2 Water Level Comparison

2.6 SENSITIVITY ANALYSIS FOR RESISTANCE FACTOR (MANNING *n*)

The Los Angeles River channel in near proximity of Taylor Yard has areas with dense bed vegetation. Analysis of different channel resistance conditions was conducted. As a base scenario, the resistance numbers established through model fitting were used. The base scenario was compared with results from scenarios using a 30% increase/decrease of the fit (calibrated) resistance numbers, a range of 0.0217-0.0403 at Taylor Yard, and 0.0112-0.0208 elsewhere. A comparison of the results is shown in Figure 2-4. The changes in water surface elevation are quite significant: up to +3.5 ft for the higher resistance factor and –2.7 ft for the lower resistance factor. This indicates considerable model sensitivity to the resistance numbers used, and suggests the need for further investigation into this variable if this project proceeds further.

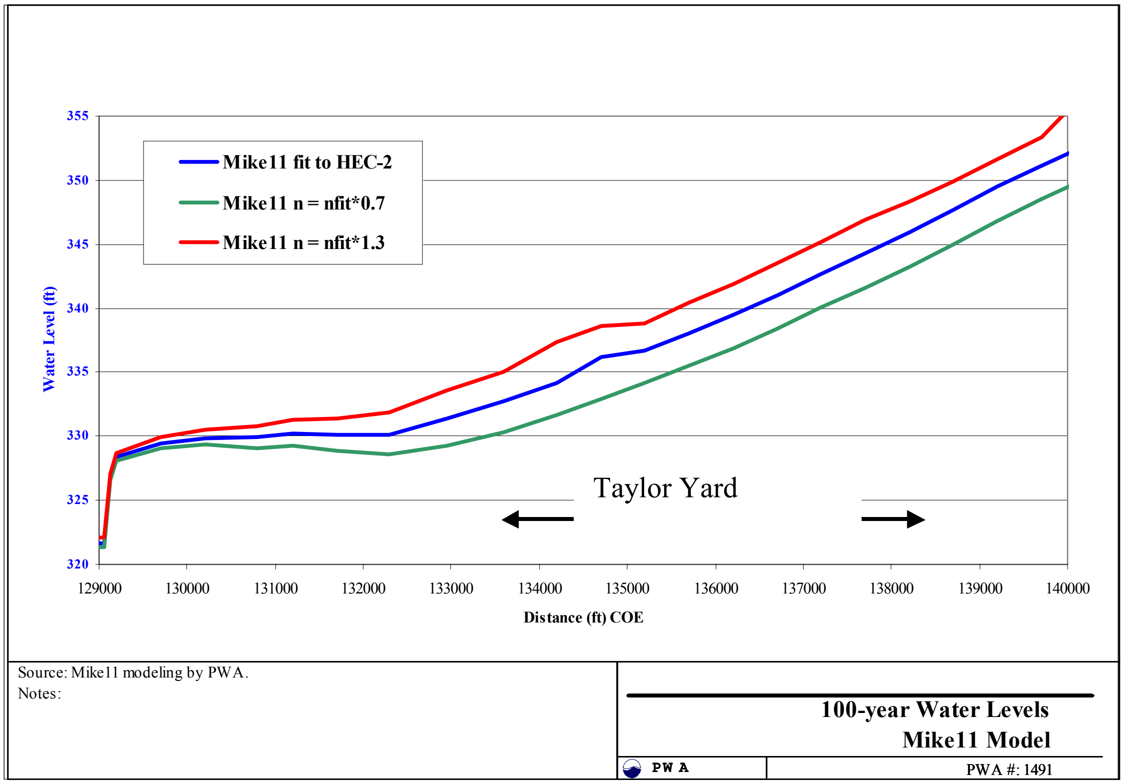


Figure 2-4. Impact of the increased/decreased channel resistance on the water surface profile

2.7 REPRESENTATION OF ALTERNATIVES

For modeling purposes, it was necessary to define certain physical characteristics of the Taylor Yard geometry and hydraulic connection to the river. Alternatives 1A and 2 were represented in the hydrodynamic model as excavated floodplain with a branch flow path connected to the Los Angeles River at the upstream end by a weir. The weir was modeled at an elevation of 337.93 feet (103 m) and 492.13 feet (150 m) in length. The elevation was selected to have a significant impact on the simulated 100-year flood hydrograph adjacent to the site; no changes to the levee system downstream of this weir were included. Alternative 4 was developed to examine the effect of channel widening of 500 – 700 feet at the Taylor Yard site for a distance of approximately 3,000 feet, as shown in Figure 2-5. Transitions to the existing channel over approximately 800 feet were included at each end of the modified reach. For Alternative 4, no separate floodplain flow path was modeled; instead, the channel was simply enlarged at this location to include the site.

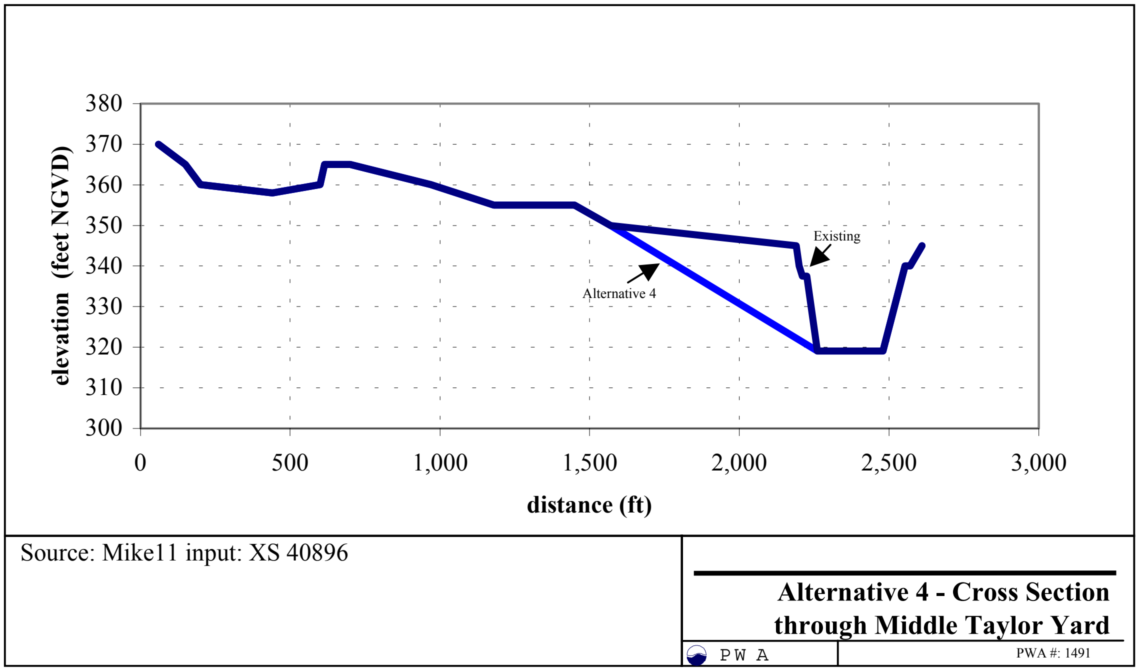


Figure 2-5. Cross section through middle Taylor Yard

Alternative X10 was designed to assess the amount of storage necessary to significantly reduce flood peaks on the Los Angeles River. For this purpose, the equivalent of the maximum storage available at Taylor Yard (using both parcels D and G) was added at nine locations between Taylor Yard and Rio Hondo, which were defined as becoming effective at elevations somewhat lower than the 100-year flood event and above. This approach creates the equivalent of an adjacent storage volume (depth over an area # 90 acres) that fills as the water in the channel rises and empties as the water level in the channel falls. Use of this technique does not account for any local energy losses, overbank flow constriction, or momentum exchange between the channel and floodplain.

The locations of these additional theoretical storage areas are shown on Figure 2-6.

Each additional fictive "Taylor Yard" area was added to represent potential flood storage. Because no real data are available, simplified schematization was used. In nine randomly chosen locations besides Taylor Yard, additional storage was added to the existing channel.

Figure 2-6. Layout for Alternative X10

3. RESULTS AND DISCUSSION

3.1 FLOODING CONDITION AT TAYLOR YARD

Flow conditions in the Los Angeles River, crest elevation of the side weir and bank elevation at Taylor Yard are the major factors affecting inflow and outflow, time of flooding and flood transformation. The crest of the side weir is a major factor impacting flood wave transformation. If the elevation is too low, the flooding will start too soon and flood storage area will be filled before the peak flow condition at the river. Alternatively, if the elevation is too high the area will be flooded only during the major events like a 100-year flood or higher. The exact configuration of the side weir is part of the further detailed optimization that will be required, but for this analysis a weir elevation of 337.93 feet (103 m) and a crest length of 492.13 feet (150 m) were assumed. The elevation was chosen after testing several potential elevations; the one with the largest effect on the 100-year peak flow was selected. The weir would be located at the upstream end of Taylor Yard, as indicated by the light blue arrow in Figure 3-1 below. The Los Angles River flows are shown with a dark blue arrow and the flow in and out from the Taylor Yard is indicated in light blue, green and pink.

At approximately 55,000–60,000 cfs, the water levels in the Los Angles River are high enough to overflow the side weir and start flooding (Figure 3-2). The flows enter the area at the upstream end (at the side weir) and partially in the middle (bank overflow) and leave the area at the downstream end. For Alternative 1A the peak flow entering the site is approximately 13,000 cfs. The combined peak outflows are approximately 12,000 cfs (Figure 3-3). Because the Taylor Yard area also slightly shifts the timing of the flood flows, the final flood wave peak attenuation is approximately 3,000 cfs.

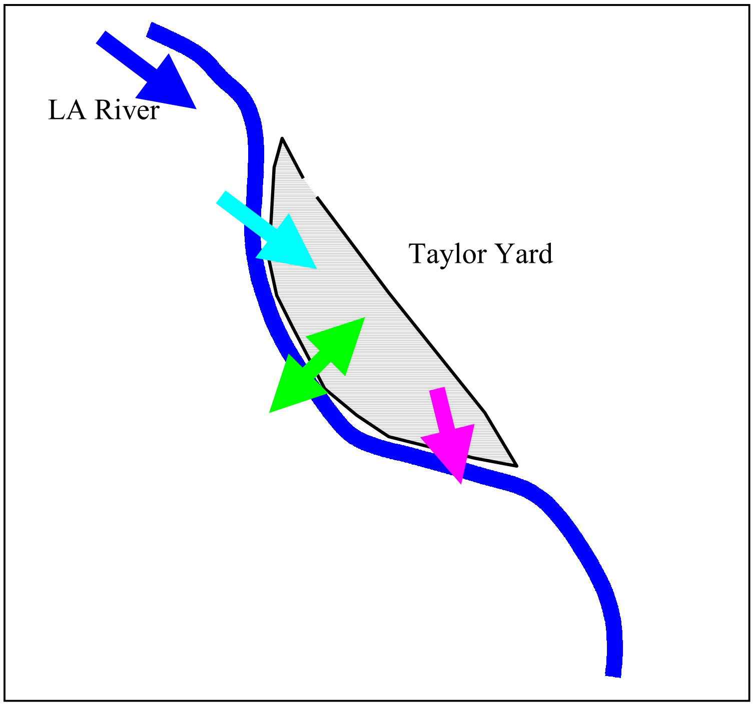


Figure 3-1. Hydraulic Schema of Taylor Yard

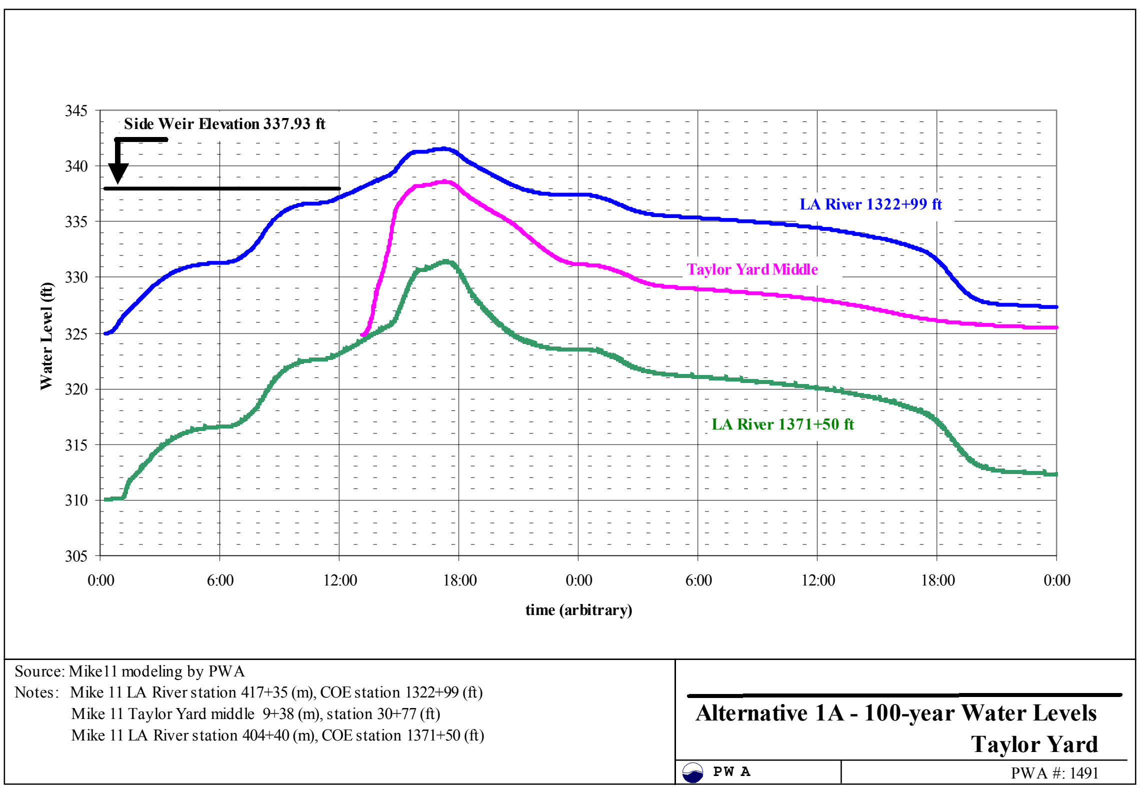
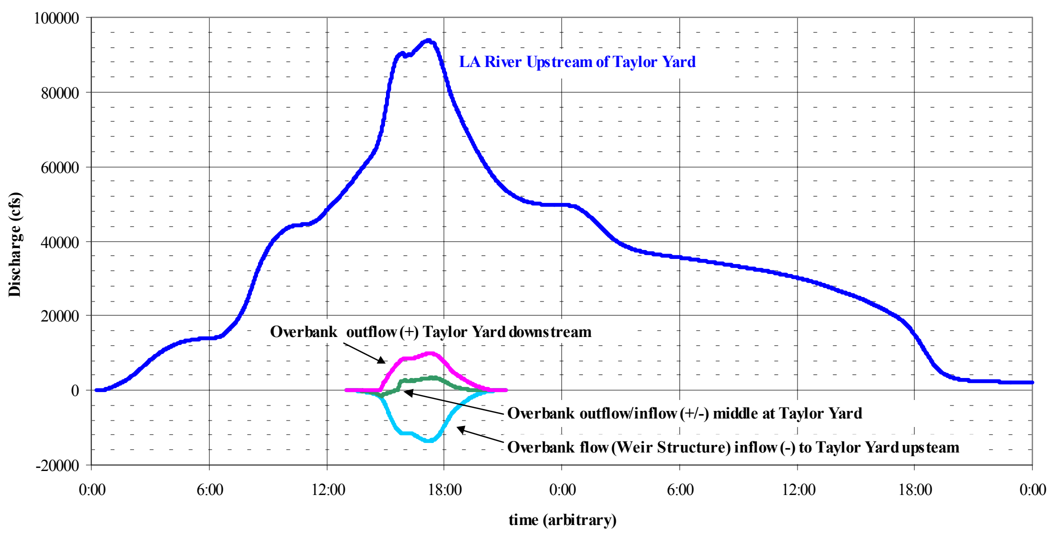


Figure 3-2. Alternative 1A: Water Levels at Taylor Yard and the Los Angeles River



Source: Mike11 modeling by PWA
Notes:

Alternative 1A - 100-year Discharge
Taylor Yard

Figure 3-3. Alternative 1A: 100-year Discharge at Taylor Yard

Under existing conditions and all alternatives tested, modeling results indicated the presence of a weak hydraulic jump in the vicinity of the Taylor Yard site during the 10-year, 50-year, and 100-year flood events (Figure 3-4). The type of hydraulic jump depends on the upstream Froude number, where:

$$Fr = \frac{v}{\sqrt{g \cdot \frac{A}{B}}}$$

Fr = Froude number (-)
v = velocity (m/s)
g = gravity constant (m/s^2)
A = cross sectional area (m^2)
B = channel width (m)

In close proximity of Taylor Yard, the upstream Froude number is simulated to be in the range from 1 to 1.2. In this case, the jump would be undular, taking the form of a series of standing waves. The exact position of the hydraulic jump is sensitive to the channel resistance, channel width and position of the hydraulic structures (e.g., diversion weir).

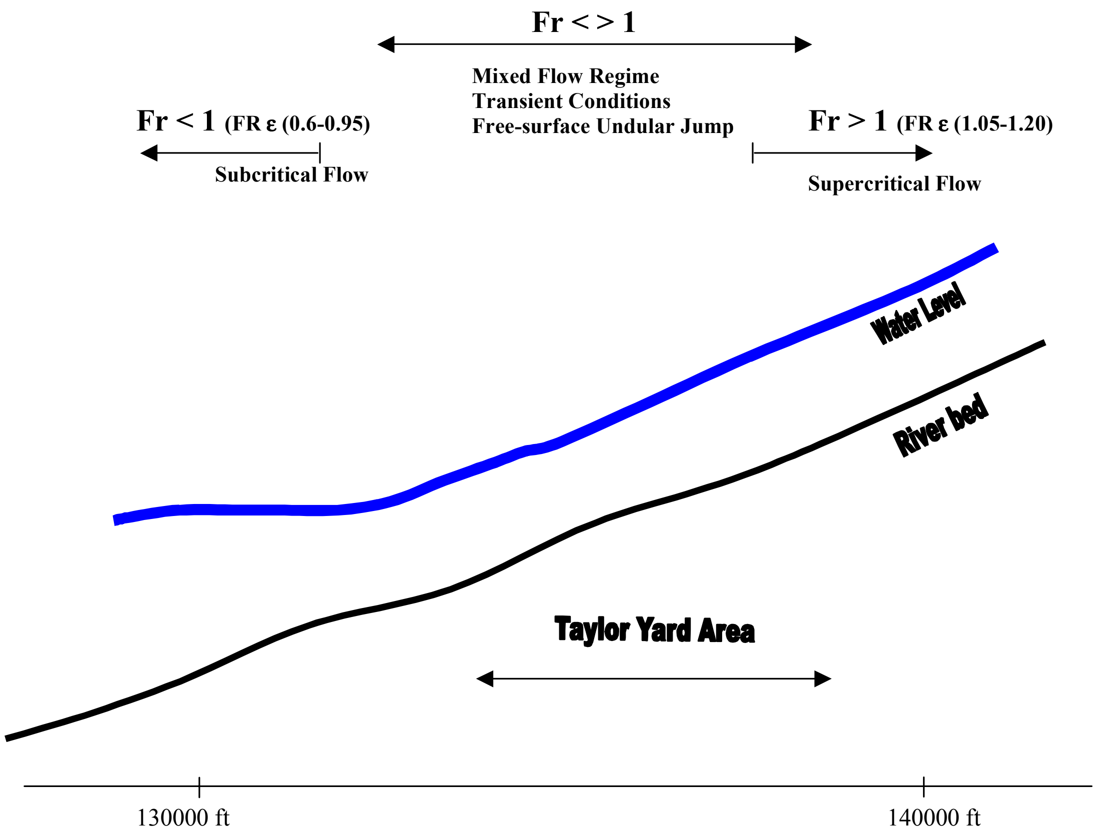


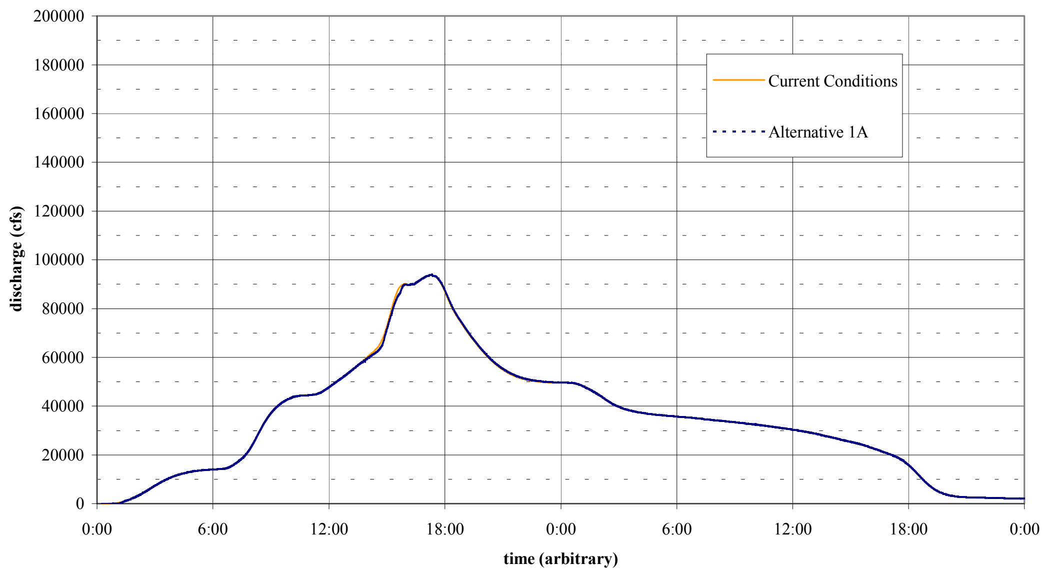
Figure 3-4. Schematic illustration of simulated mixed flow conditions

3.2 ALTERNATIVE 1A: EXCAVATION OF 970 TCY FROM TAYLOR YARD

3.2.1 100-year Flood Event

Flood storage provided by Alternative 1A slightly slowed and lowered the initial peak of the 100-year flood. Immediately downstream of Taylor Yard, the release of the stored water coincided with the second and higher flood peak, causing a slight increase in water level. Figure 3-5 through Figure 3-8 show the discharge as the flood wave progresses downstream. By the time it reaches Arroyo Seco, the first flood peak is the highest and is slightly reduced by Alternative 1A.

The 100-year water levels at each location show a similar pattern to the discharges. Below Taylor Yard, the initial peak is lower than the second peak and slightly reduced by Alternative 1A. At Arroyo Seco, the first peak is the highest and is still slightly reduced by Alternative 1A. Figure 3-9 through Figure 3-12 show the water level.



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 419+33 (m), COE station 1322+99 (ft).

Alternative 1A - 100-year Discharge Downstream of Taylor Yard

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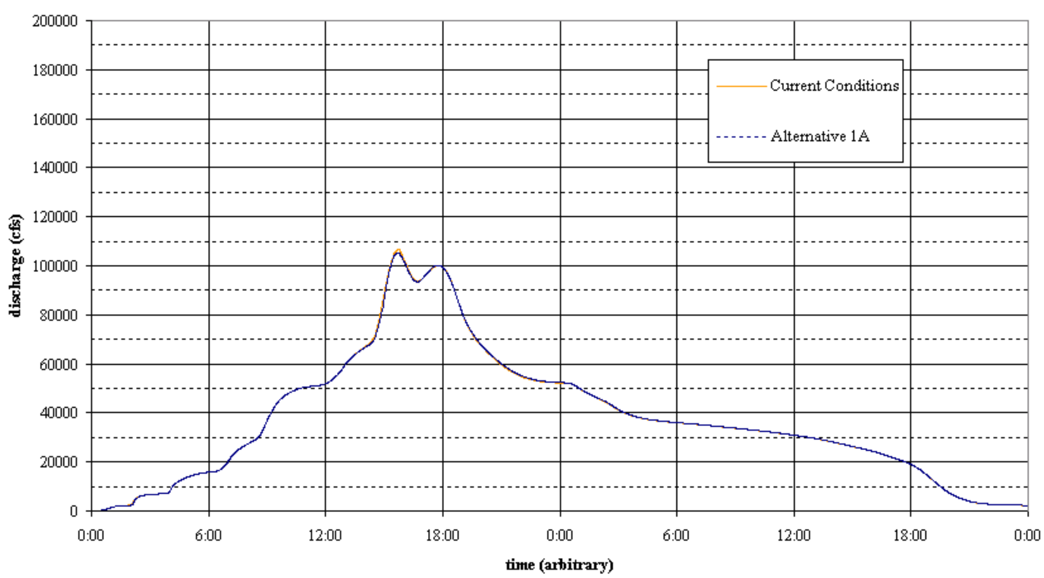
Figure 3-5. Alternative 1A: Discharge Downstream of Taylor Yard



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 442+02 (m), COE station 1248+55 (ft).

Alternative 1A - 100-year Discharge Downstream of Arroyo Seco

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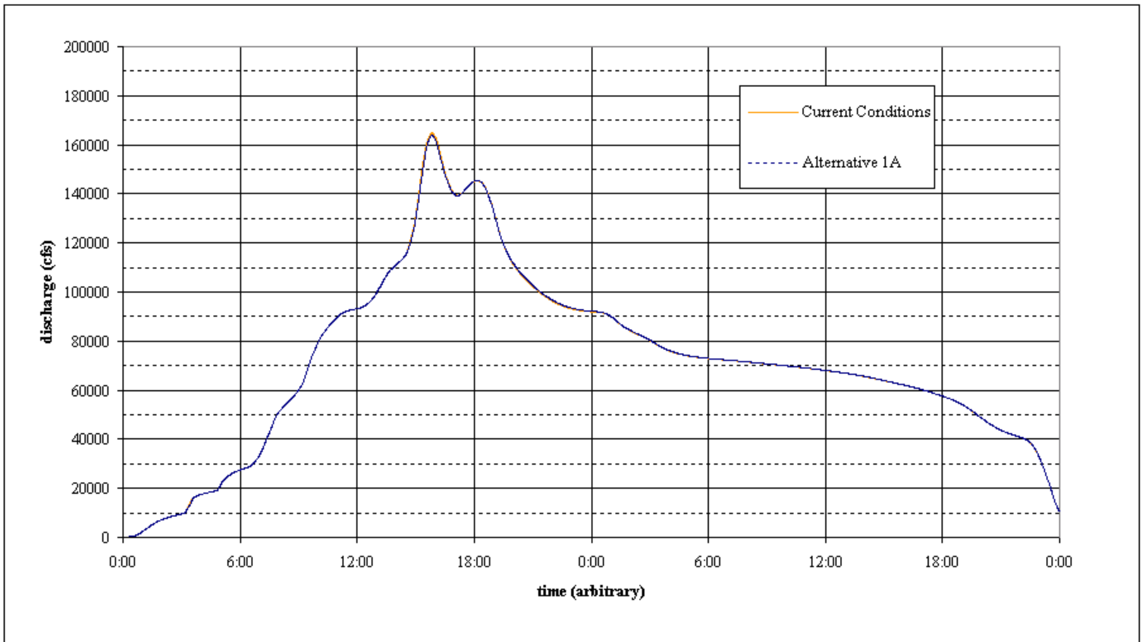
Figure 3-6. Alternative 1A: Discharge Downstream of Arroyo Seco



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 613+79 (m), COE station 684+00 (ft).

Alternative 1A - 100-year Discharge Downstream of Rio Hondo

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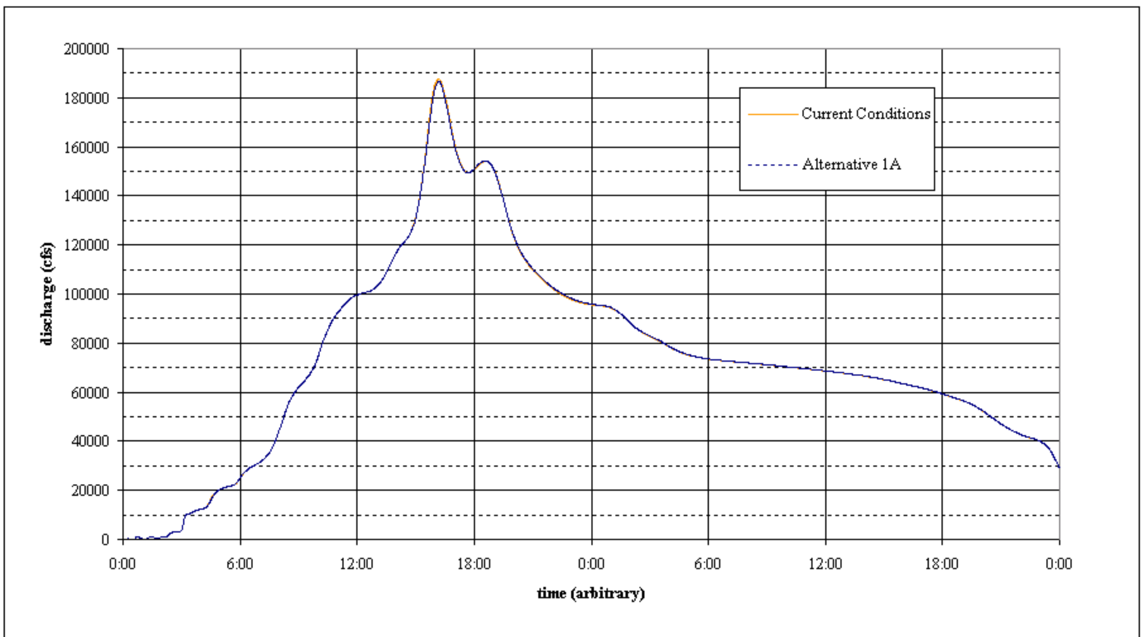
Figure 3-7. Alternative 1A: Discharge Downstream of Rio Hondo



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 815+29 (m), COE station 23+91 (ft).

Alternative 1A - 100-year Discharge Long Beach

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Figure 3-8. Alternative 1A: Discharge at Long Beach

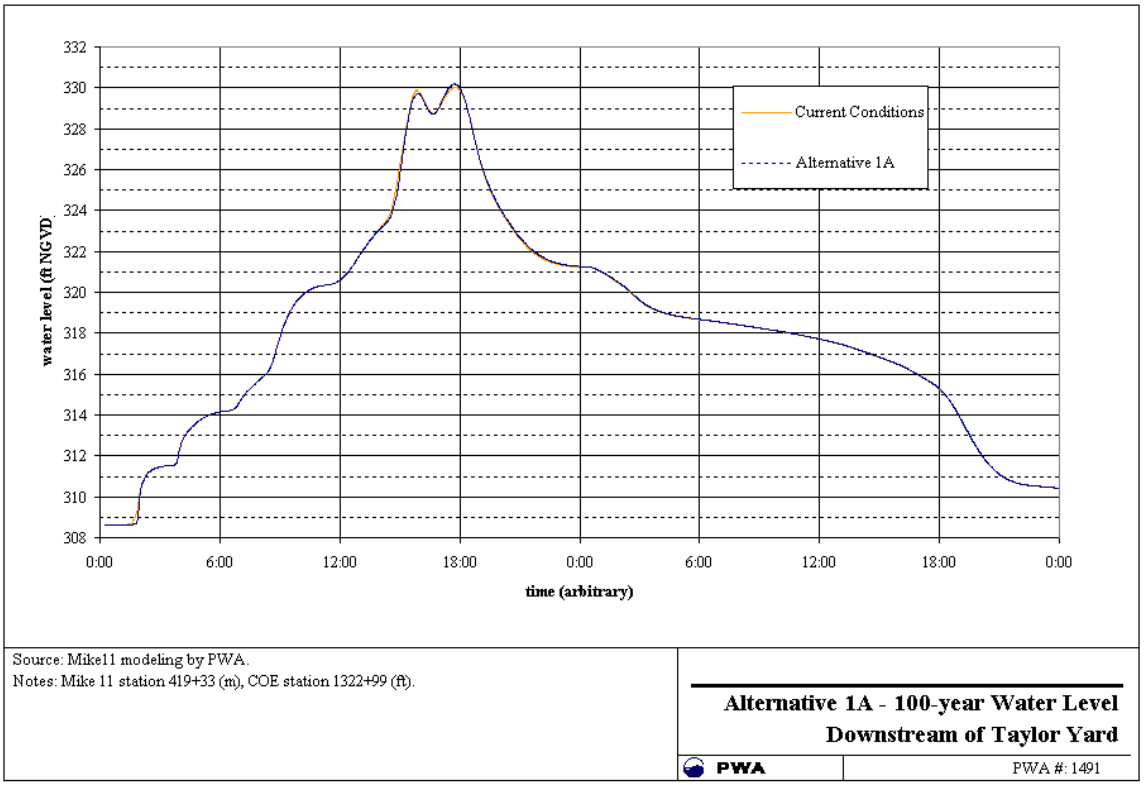


Figure 3-9. Alternative 1A: Water Level Downstream of Taylor Yard

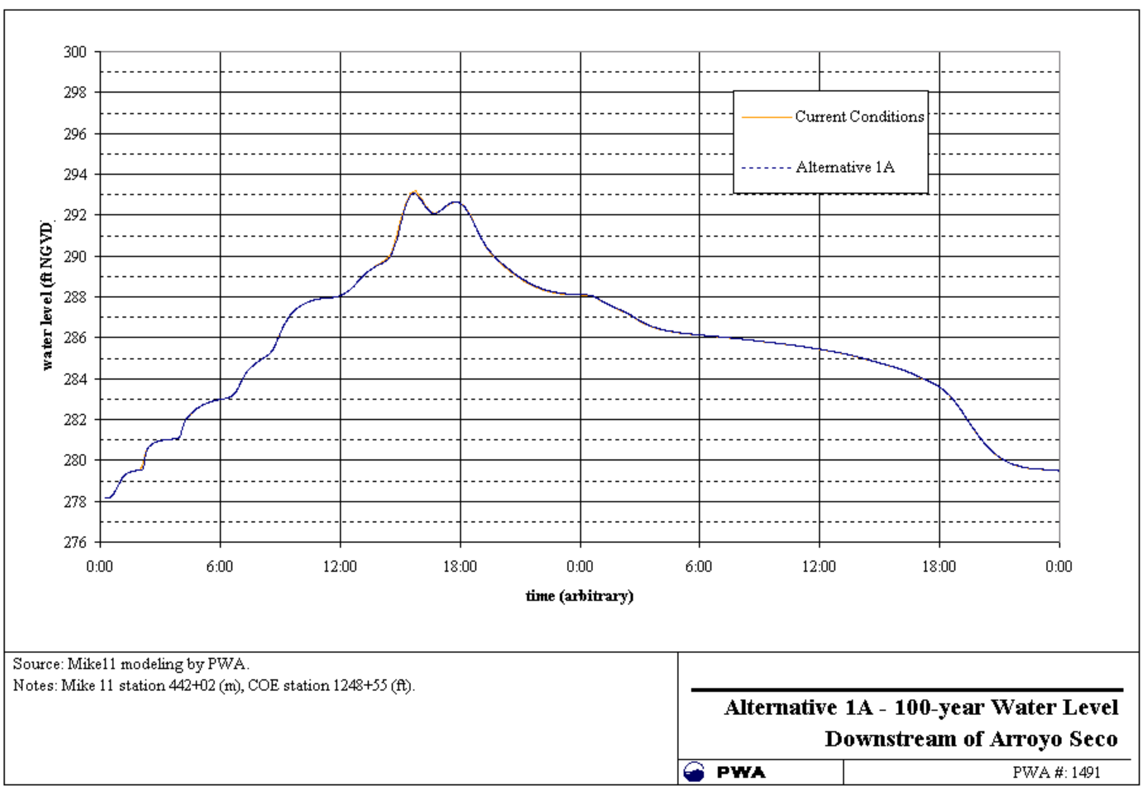
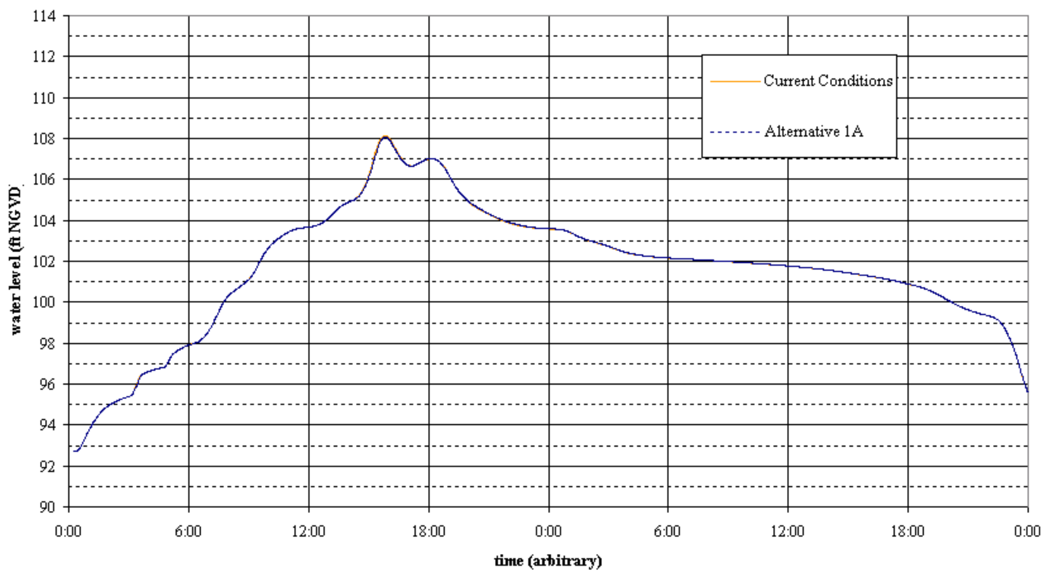


Figure 3-10. Alternative 1A: Water Level Downstream of Arroyo Seco



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 613+79 (m), COE station 684+00 (ft).

Alternative 1A - 100-year Water Level Downstream of Rio Hondo

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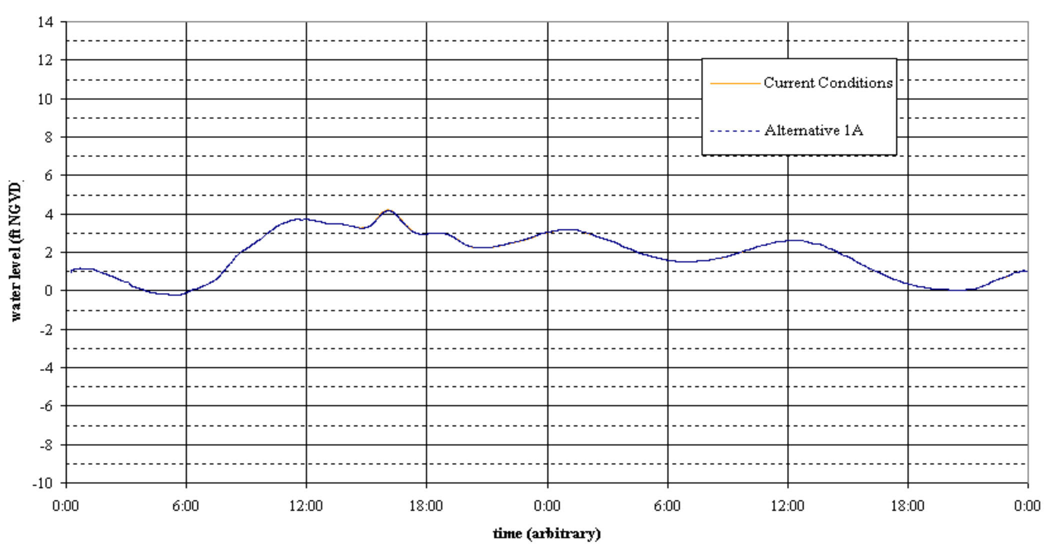
Figure 3-11. Alternative 1A: Water Level Downstream of Rio Hondo



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 815+29 (m), COE station 23+91 (ft).

Alternative 1A - 100-year Water Level Long Beach

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Figure 3-12. Alternative 1A: Water Level at Long Beach

The maximum change in discharge between existing conditions and Alternative 1A is a reduction of 3,000 cfs and occurs immediately downstream of Taylor Yard. It coincides with the maximum change in water level of approximately 0.6 feet. Approximately 1.5 hours after the maximum change, the discharge difference is close to zero. Differences between the water levels, on the other hand, are out of phase with the discharge and reach about 0.3 feet. Since the Froude number is close to 1.0, the threshold for supercritical flow, the phase difference between discharge and water level likely indicates a mixed flow regime. As discharge decreases, the flow shifts to a subcritical regime and depth increases. Conversely, as the discharge increases, the flow shifts to a supercritical regime and depth decreases. Differences in discharge and water level relative to simulated existing conditions decrease as the flood wave progresses downstream, and they are in phase, as shown in Figure 3-13 through Figure 3-16.

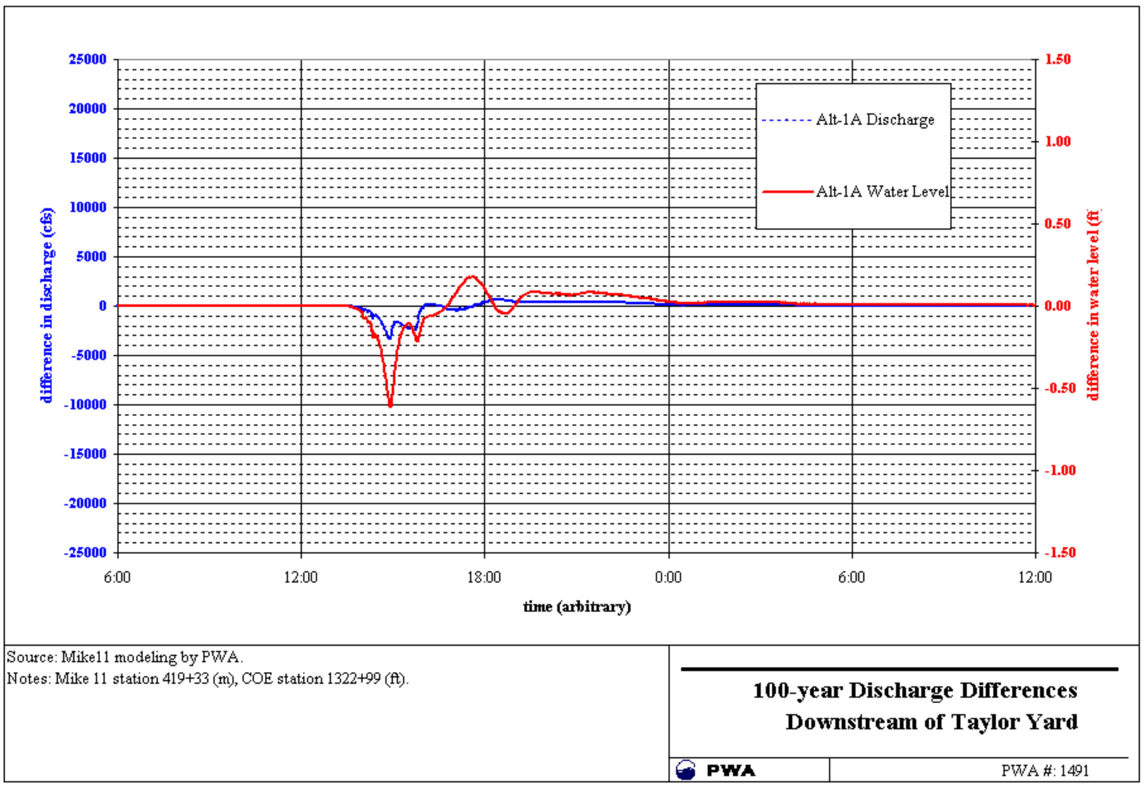


Figure 3-13. Alternative 1A: Discharge Differences Downstream of Taylor Yard

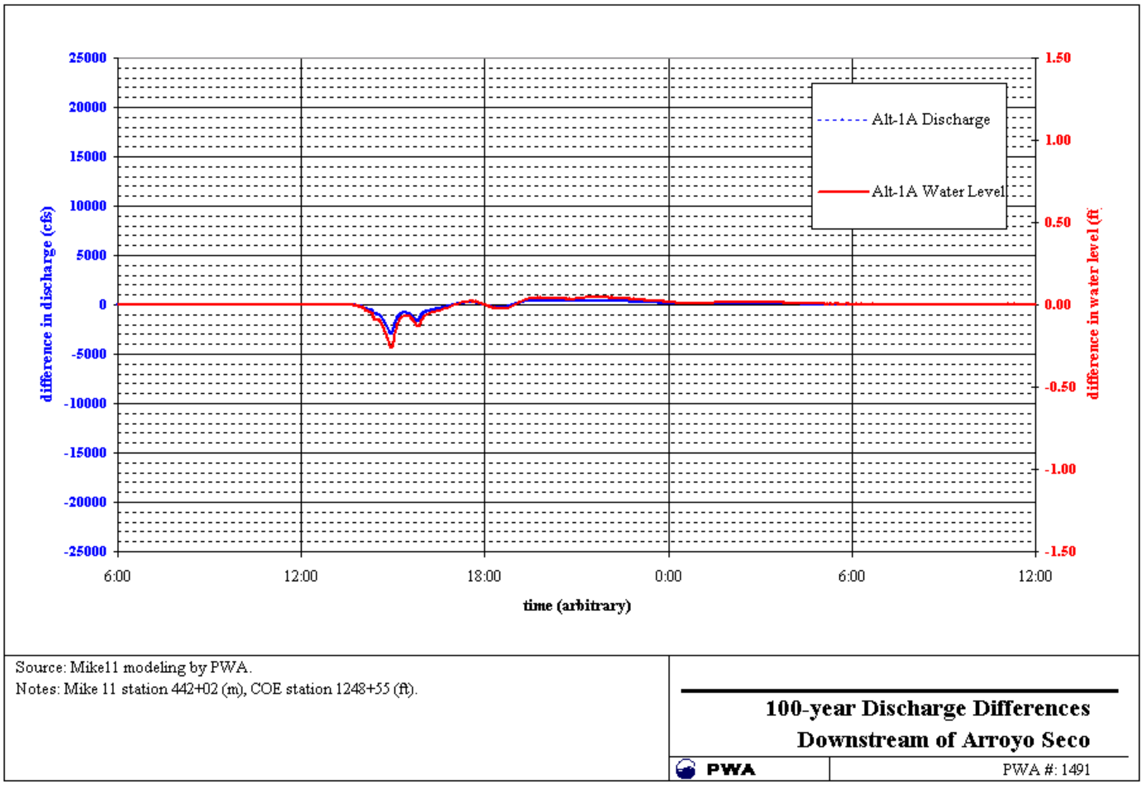


Figure 3-14. Alternative 1A: Discharge Differences Downstream of Arroyo Seco

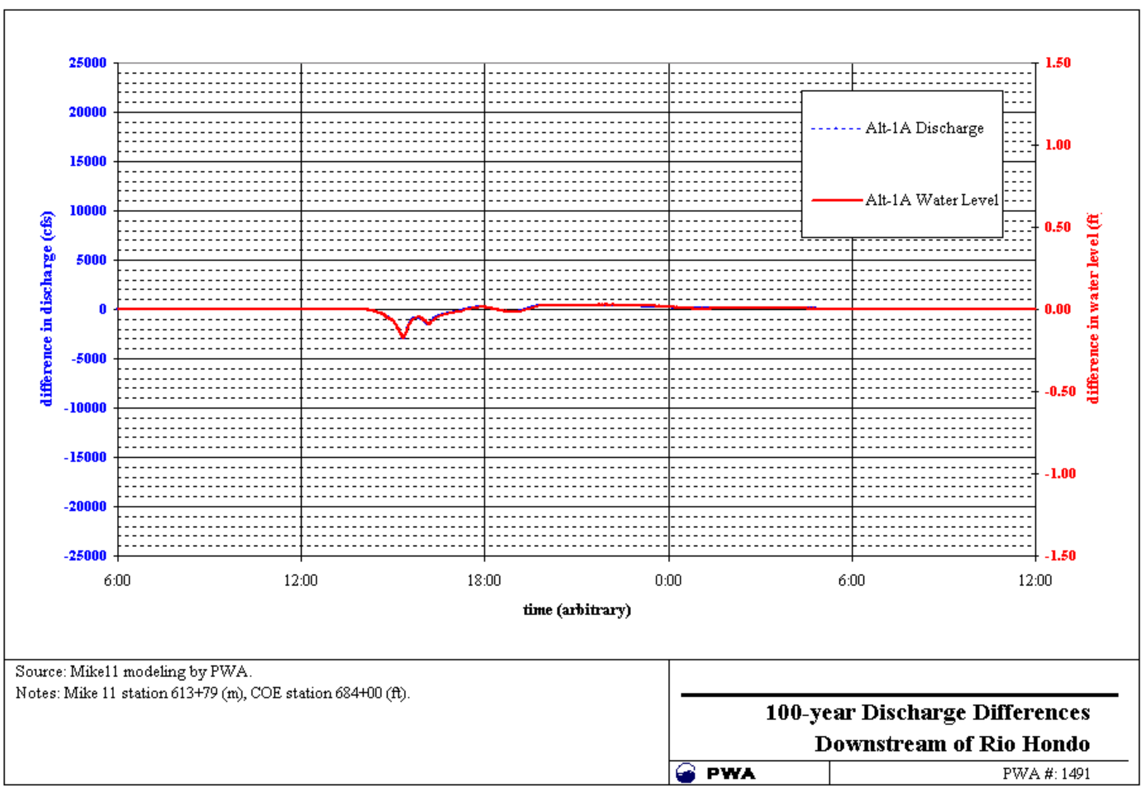


Figure 3-15. Alternative 1A: Discharge Differences Downstream of Rio Hondo

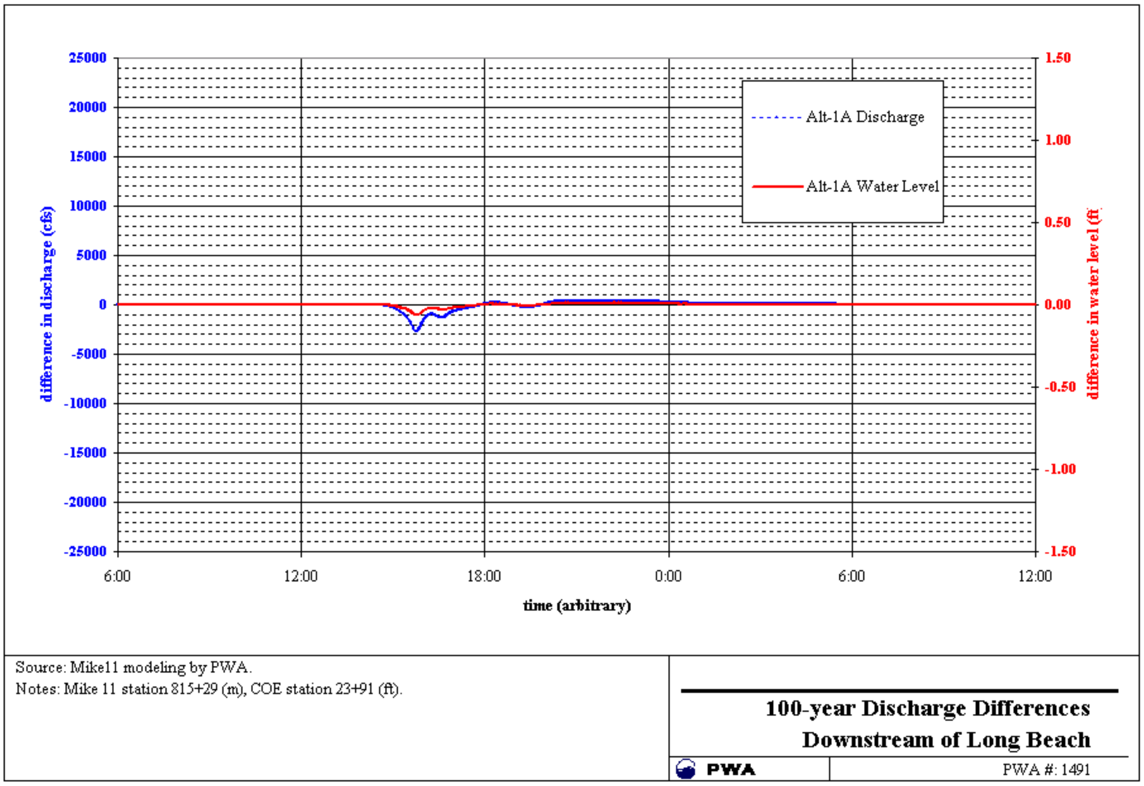


Figure 3-16. Alternative 1A: Discharge Differences at Long Beach

3.2.2 50-year, 10-year, and 5-year Flood Events

The 50-year peak discharge and water level were reduced with Alternative 1A (Figure 3-17 and Figure 3-18). Discharge was reduced by about 4,000 cfs, while the water level was lowered approximately 0.4 feet (Figure 3-19). Alternative 1A had no effect on the 10-year and 5-year flows.

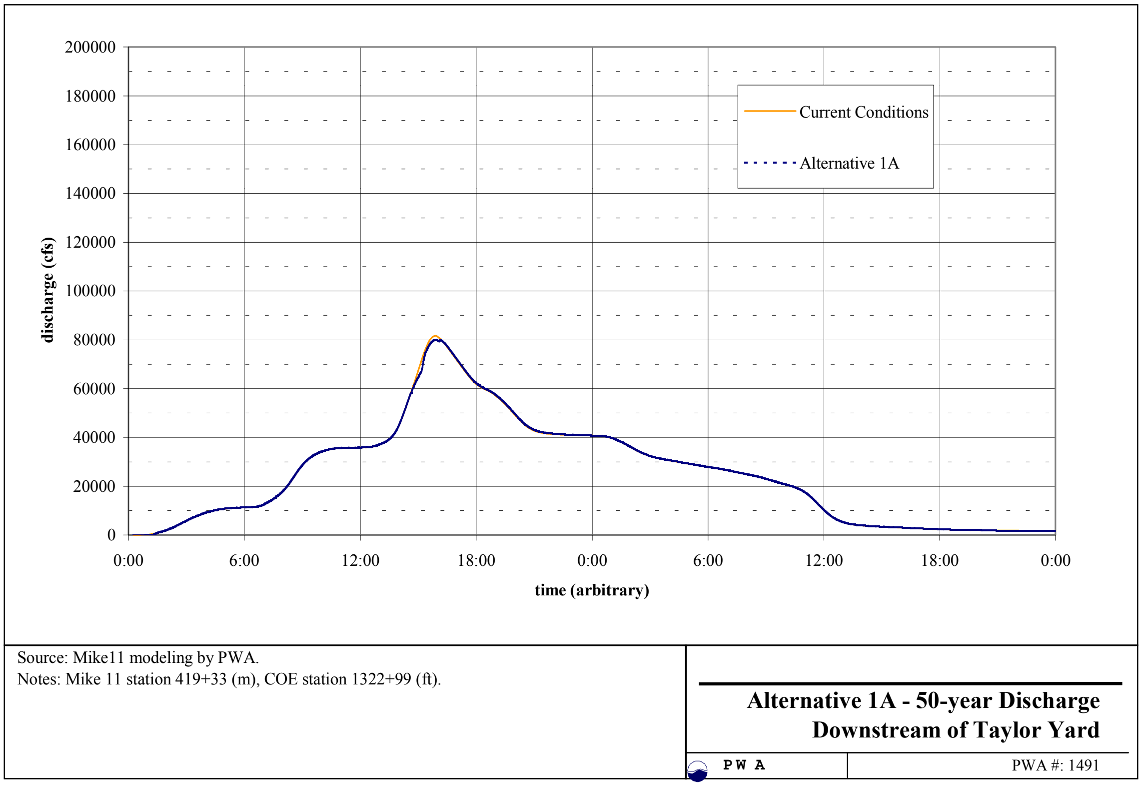


Figure 3-17. Alternative 1A: 50-year Discharge Downstream of Taylor Yard

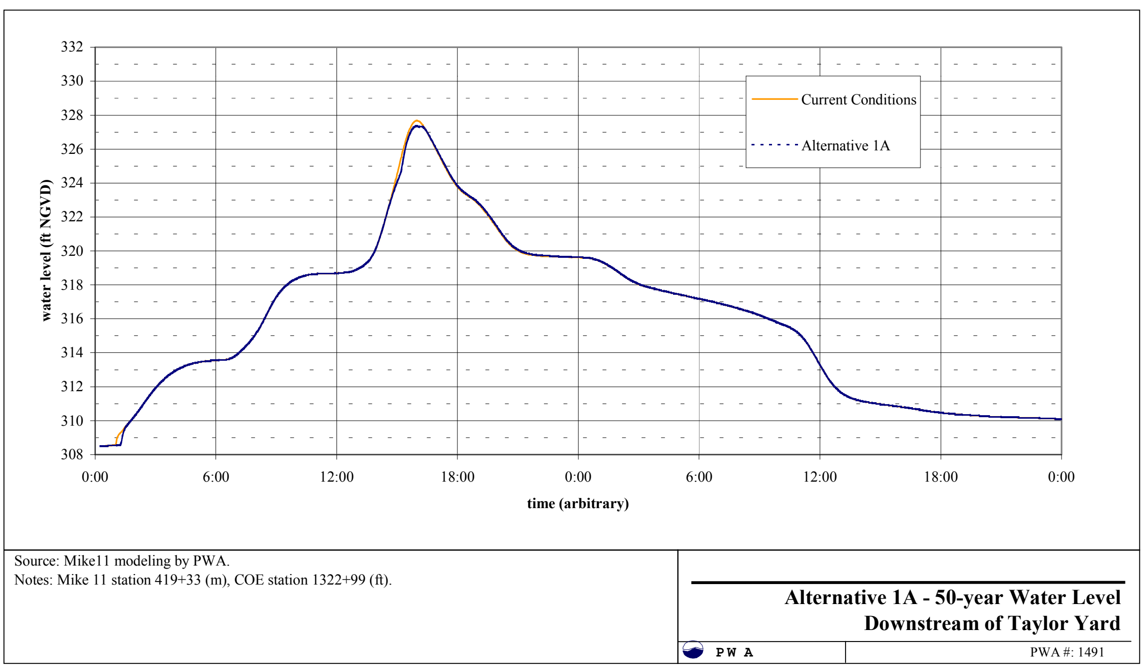
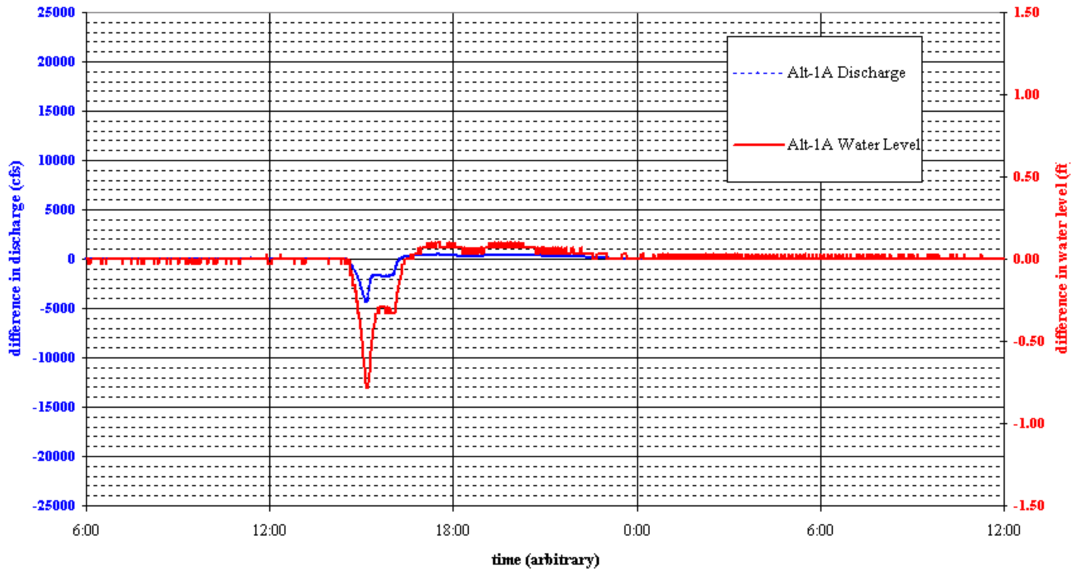


Figure 3-18. Alternative 1A: 50-year Water Level Downstream of Taylor Yard



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 419+33 (m), COE station 1322+99 (ft).

50-year Flow Differences Downstream of Taylor Yard

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Figure 3-19. Alternative 1A: 50-year Flow Differences Downstream of Taylor Yard

3.3 ALTERNATIVE 2: EXCAVATION OF 620 TCY FROM TAYLOR YARD

3.3.1 100-year Flood Event

Alternative 2 was evaluated for its effect on the 100-year flood hydrograph even though it was not conceived of as a flood management effort. Consequently, the effect of Alternative 2 on discharge and water level from a 100-year event was less than Alternative 1A when compared to simulated existing conditions (Figure 3-20). Changes in discharge showed a similar pattern to Alternative 1A with an initial decrease followed by a smaller increase within a few hours. The maximum change was 1000 cfs. The differences in water level followed a slightly different pattern from Alternative 1A. The initial reduction in discharge did not lead to lower water levels. Instead, the changes in water levels were out of phase with changes in discharge throughout the entire time that differences were present, indicating a mixed flow regime. As the flood wave traveled downstream, these changes decreased.

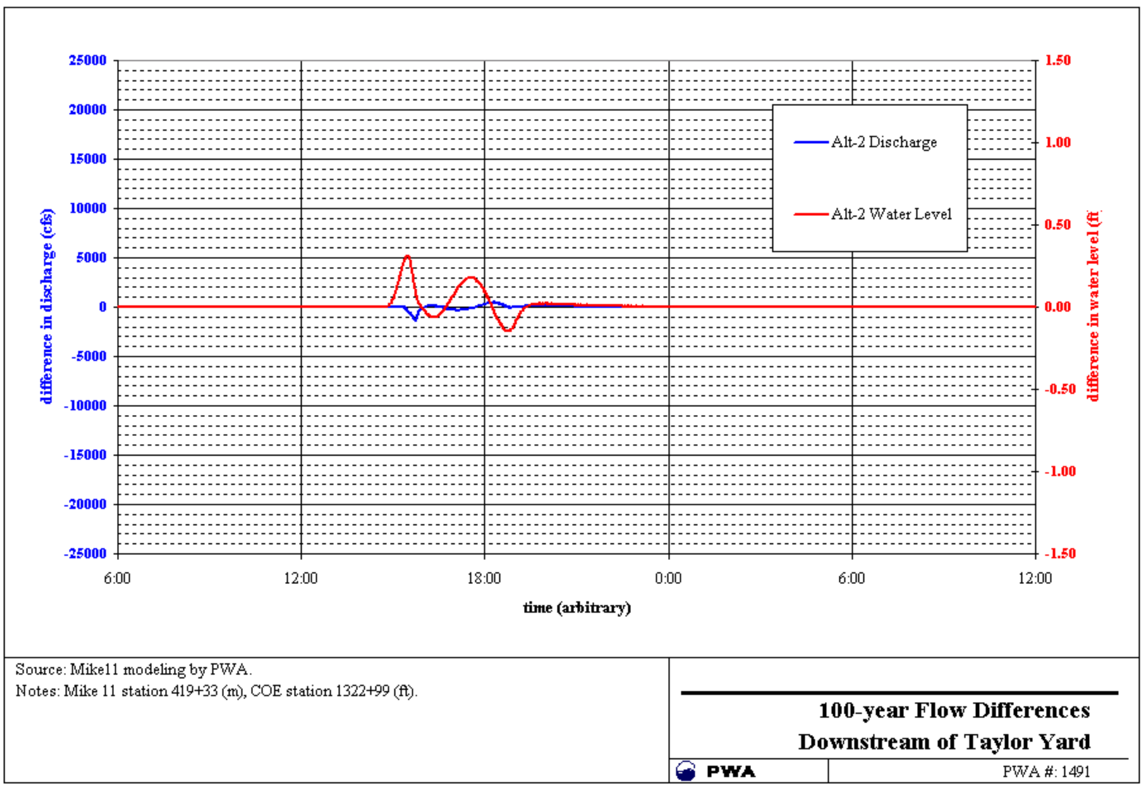


Figure 3-20. Alternative 2: 100-year Flow Differences Downstream of Taylor Yard

3.3.2 50-year, 10-year, and 5-year Flood Events

Alternative 2 had a slight impact on the water level of a 50-year flood, causing the change in water level to fluctuate around 0.1 feet (Figure 3-21). It had no effect on the 10-year and 5-year events.

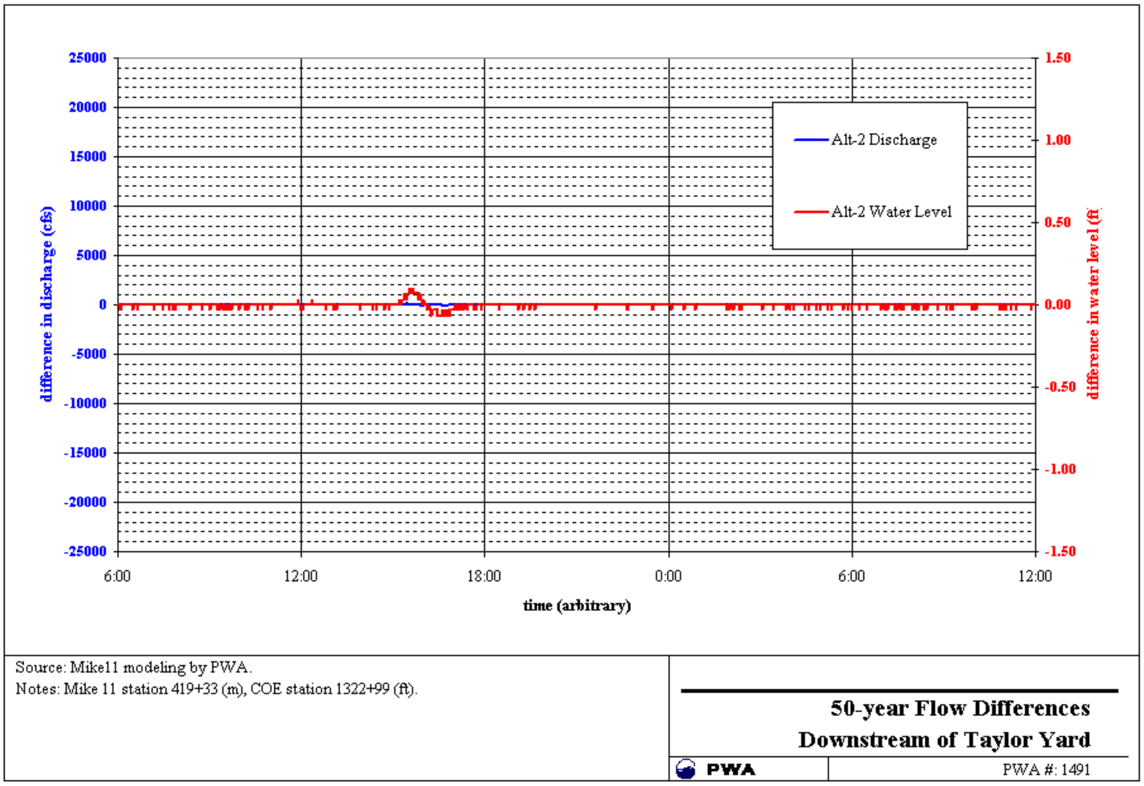


Figure 3-21. Alternative 2: 50-year Flow Differences Downstream of Taylor Yard

3.4 ALTERNATIVE 4: EXCAVATION OF 890 TCY FROM RIVER CHANNEL

3.4.1 100-year Flood Event

Effects on 100-year discharge and water level due to Alternative 4 were relatively small and similar to the Alternative 2 results. These findings suggest that the length of channel being widened may be insufficient to significantly change flood hydraulics in this reach of the river. The maximum change in discharge was only around 1,000 cfs and was out of phase with the water level, indicating a mixed flow regime (Figure 3-22). Further downstream, the changes relative to simulated existing conditions decreased.

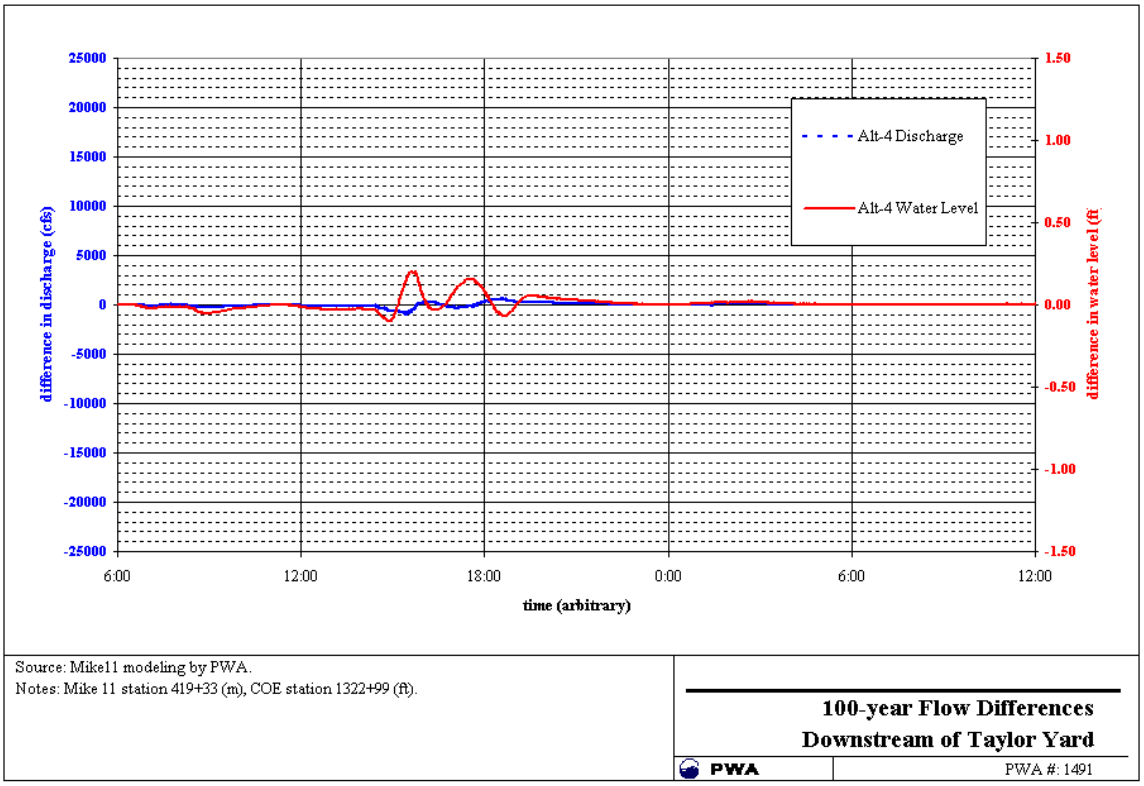
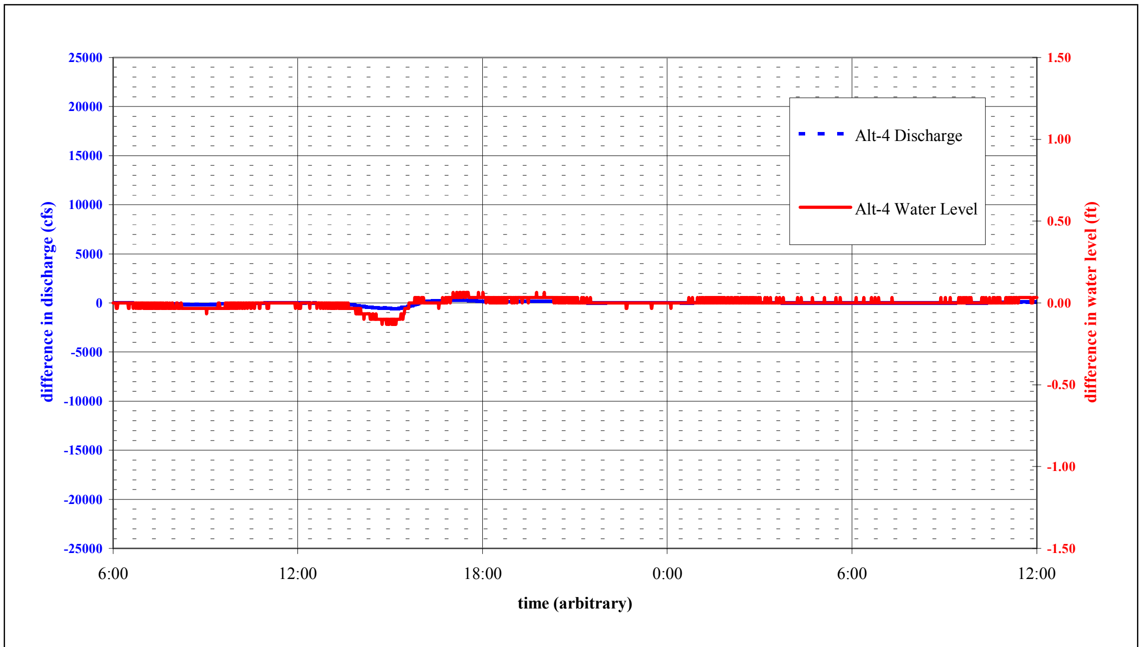


Figure 3-22. Alternative 4: 100-year Flow Differences Downstream of Taylor Yard

3.4.2 50-year, 10-year, and 5-year Flood Events

Alternative 4 caused a slight reduction in discharge and water level that gradually decreased in magnitude for the 50-year, 10-year, and 5-year events (Figure 3-23 through Figure 3-25). The 50-year discharge was reduced by approximately 500 cfs and the water level lowered about 0.2 feet.



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 419+33 (m), COE station 1322+99 (ft).

**50-year Flow Differences
Downstream of Taylor Yard**

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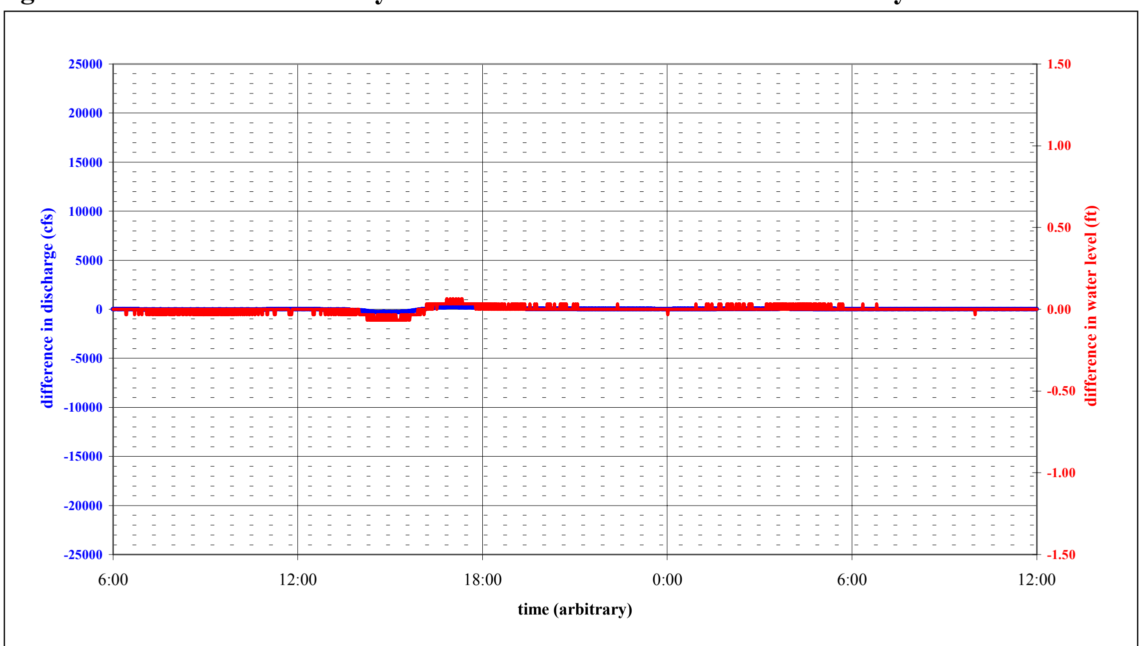
Figure 3-23. Alternative 4: 50-year Flow Differences Downstream of Taylor Yard



Source: Mike11 modeling by PWA.
Notes: Mike 11 station 419+33 (m), COE station 1322+99 (ft).

**10-year Flow Differences
Downstream of Taylor Yard**

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Figure 3-24. Alternative 4: 10-year Flow Differences Downstream of Taylor Yard

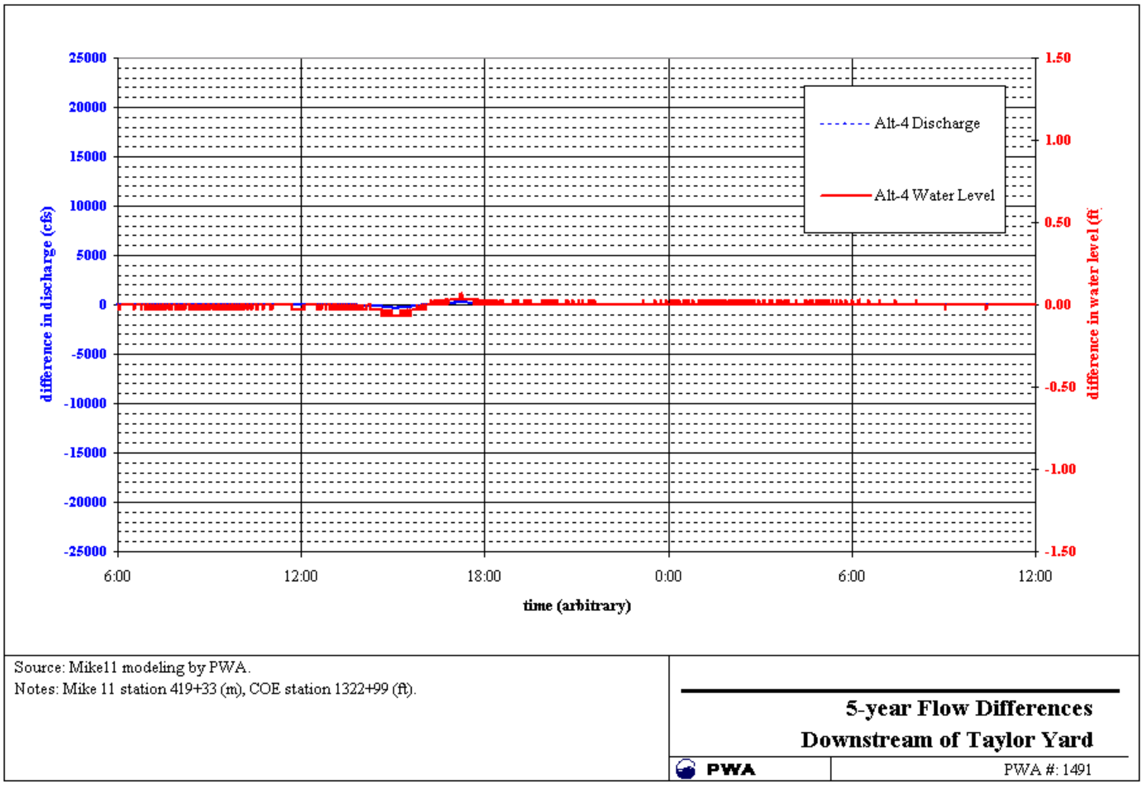

Figure 3-25. Alternative 4: 5-year Flow Differences Downstream of Taylor Yard

3.5 MAXIMUM VELOCITY DURING FLOOD EVENTS FOR ALTERNATIVES 1A, 2 AND 4

Maximum velocities during the 100-year flow event were evaluated for each alternative. The maximum average cross-sectional velocities in the Taylor Yard floodplain for Alternative 1A are in the range of 10 - 20 ft/s. High velocity conditions are observed in the first short time period of flooding when the water depth is the range of 0.2 - 1.5 ft. As the water depth increases (2 or more feet), the velocities decrease into range of 5 - 8 ft/s. The lower part of Taylor Yard and the adjacent Parcel D are in a backwater condition with flow velocities not higher than 1 - 3 ft/s (Figure 3-26).

The detailed analysis of velocity field conditions was not included in this study and would require 2-D or 3-D modeling to accomplish. It is clear, however, that energy dissipation downstream of the side weir and bank overflow needs to be considered in bed and bank protection planning.

Maximum average cross sectional velocities for Alternative 2 are in the range of 3 - 7 ft/s. In comparison to Alternative 1A, weir and bank overflow is not as dynamic because the area has higher floodplain elevations.

Alternative 4 will decrease velocities in the Los Angeles River channel by 2-5 ft/s due to the larger cross sectional area (Figure 3-27). Higher flow velocities upstream of Taylor Yard are the result of the changes in water surface profile (increase in gradient).

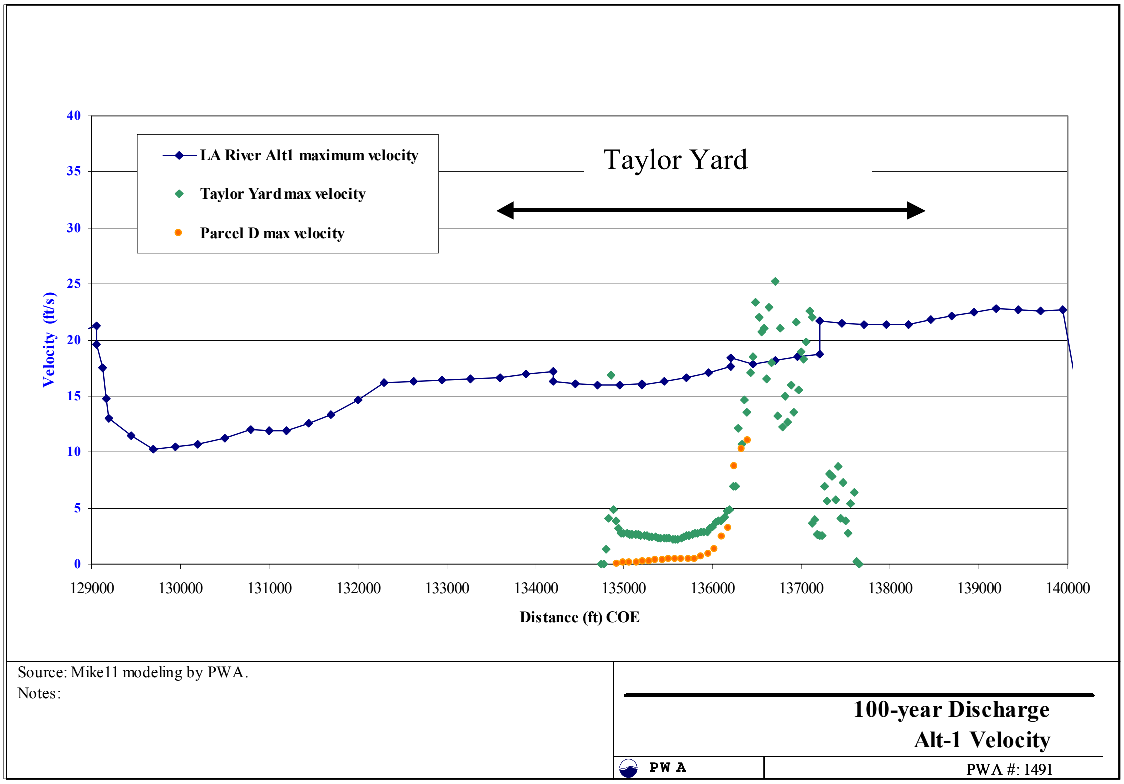

Figure 3-26. Alternative 1A: Maximum Velocity at Los Angeles River and Taylor Yard

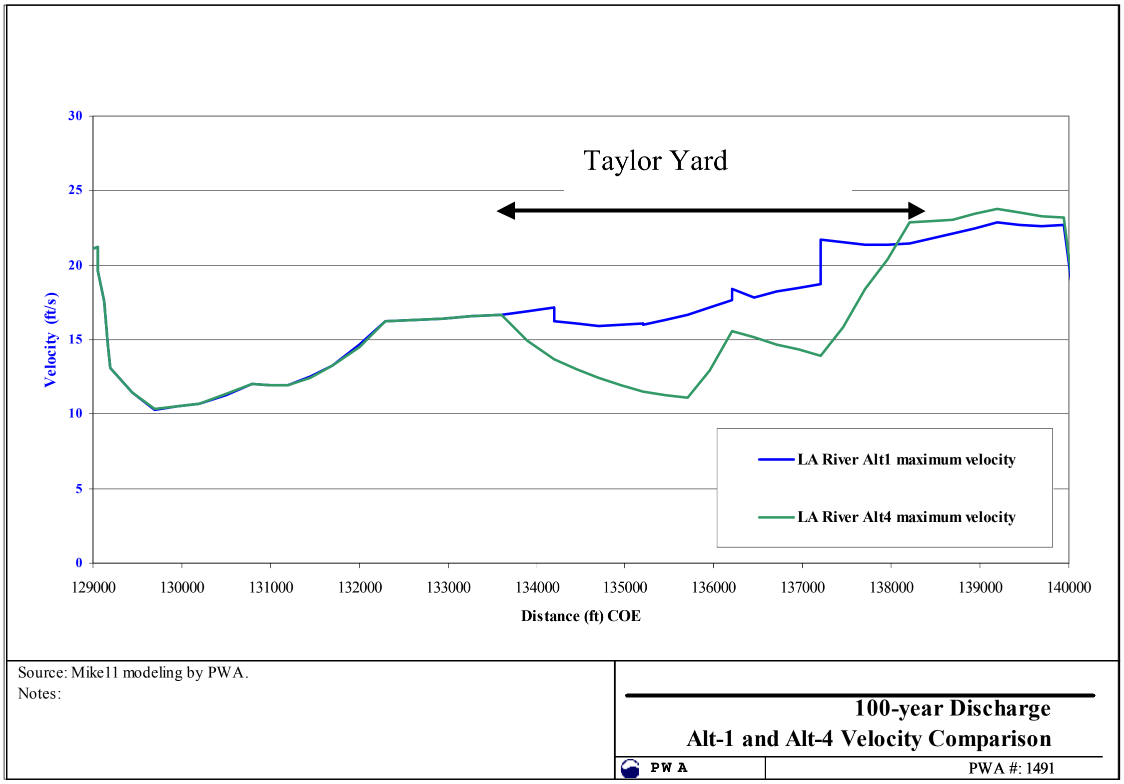

Figure 3-27. Alternative 1A and Alternative 4: River Channel Velocity Comparison

3.6 ALTERNATIVE X10: ADDITIONAL FLOODPLAIN GRADING DOWNSTREAM

The addition of nine storage areas between Taylor Yard and Rio Hondo has a significant effect on discharge and water level during a 100-year flood. As shown in Figure 3-28 and Figure 3-29, the peak flow and water level are reduced. The maximum decrease in discharge below Rio Hondo is 21,000 cfs relative to simulated existing conditions. The maximum reduction in water level of 1.2 feet occurs at the same time. Figure 3-30 shows these changes relative to simulated existing conditions below Rio Hondo.

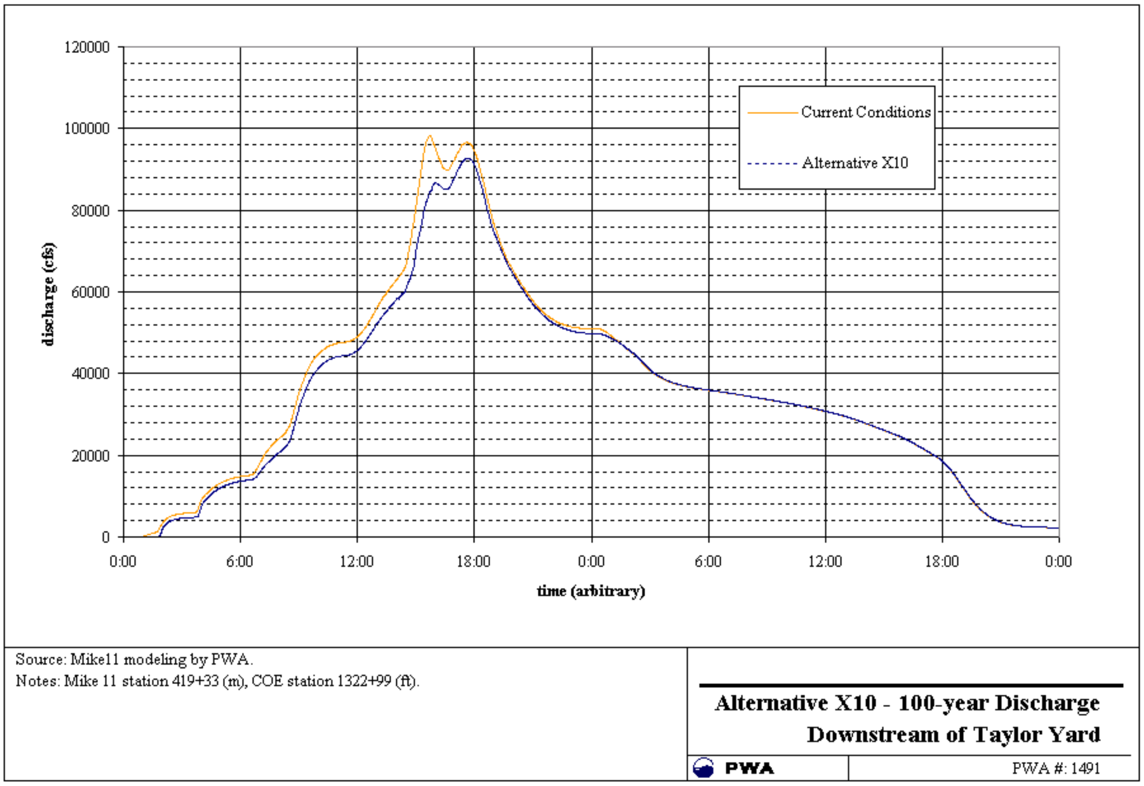

Figure 3-28. Alternative X10: 100-year Discharge Differences Downstream of Taylor Yard

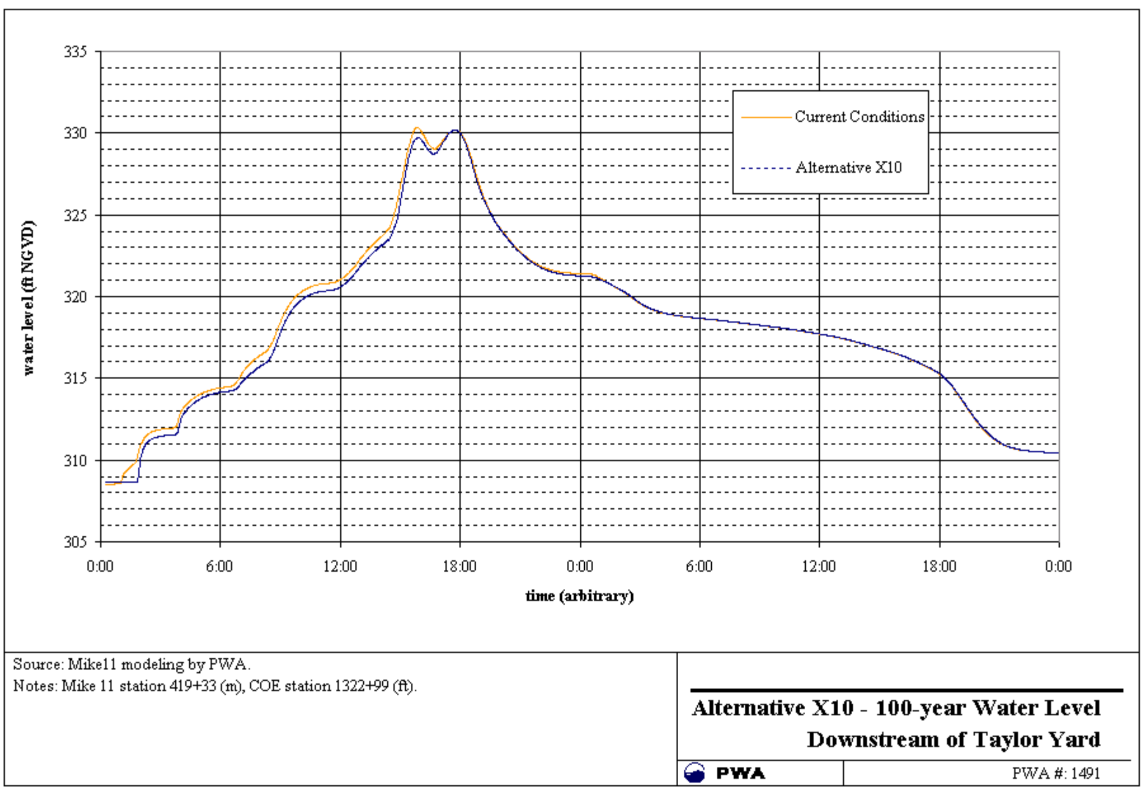

Figure 3-29. Alternative X10: 100-year Water Levels Downstream of Taylor Yard

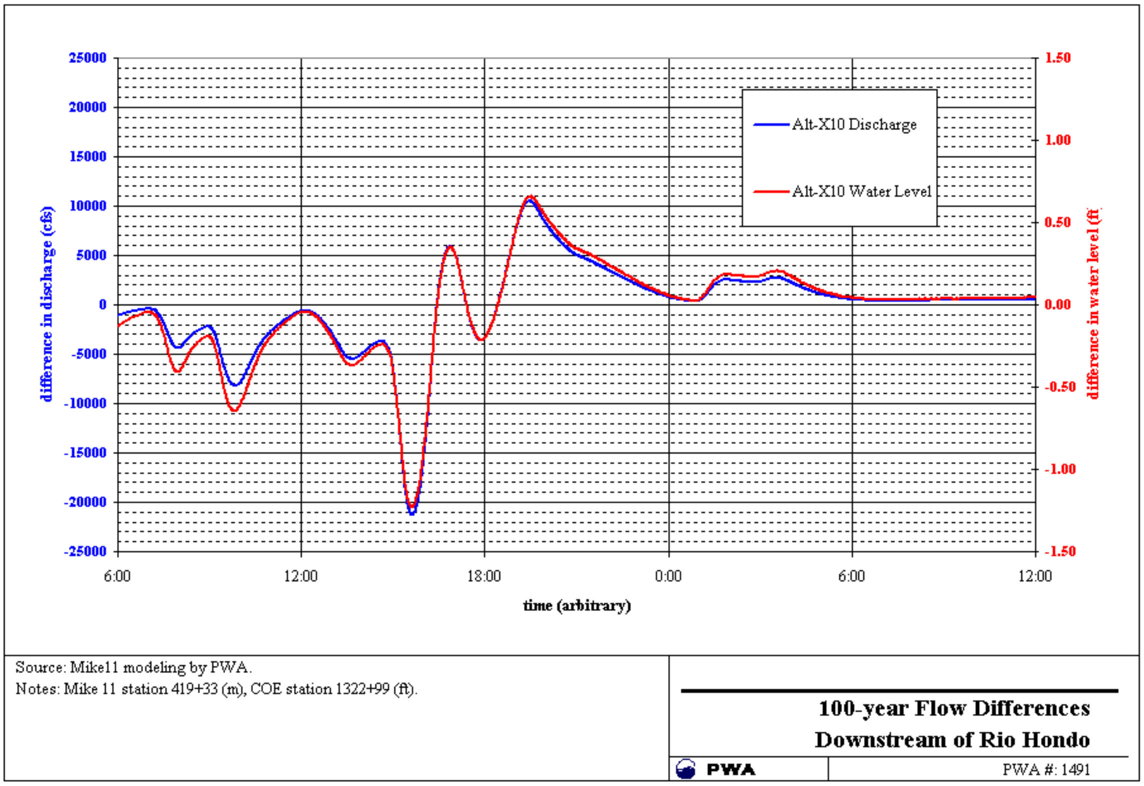

Figure 3-30. Alternative X10: 100-year Flow Differences Downstream of Rio Hondo

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

As a single project, the Taylor Yard restoration and flood storage project will have only a minor impact on flood flows. Relative to existing conditions, changes in 100-year flows are less than 4%, and changes in corresponding water depths are less than 2.5%. This is due to the limited area available at this site. Nonetheless, the results obtained for the hypothetical example of Alternative X10 indicate the potential of this approach when implemented on a large scale.

1. The hypothetical case of Alternative X10 would significantly reduce flood flows. Estimated changes in discharge were more than 10% for a 100-year storm, demonstrating the significant impact of an extensive program of floodplain restoration. Because the evaluated design was intended to affect primarily the 100-year peak flow conditions, reductions were less for smaller storm events, falling in the 0 – 5% range.
2. Alternative 1A would create the largest reduction in 100-year and 50-year flood flows relative to the other Taylor Yard alternatives evaluated. Under the concept design conditions evaluated, only Alternative 4 would cause some reduction in the 5- and 10-year flood events.
3. For Alternative 1A, average cross-sectional velocities in the Taylor Yard floodplain are in the range of 5 – 8 feet/second once the depth of flow on the floodplain reaches approximately 2 feet. As the floodplain initially fills, much higher velocities are predicted, indicating the need for energy dissipation features in the design of the system diverting water from the channel into Taylor Yard.
4. Large basin size, mixed-regime flow (both subcritical and supercritical), high channel slope, and backwater effects due to downstream bridges lead to dynamic and complex hydraulics in the Taylor Yard reach. In particular, the potential presence of a mixed flow regime at high flows in the vicinity of the Taylor Yard site means that design of any diversion structure at this location may be technically difficult. Additional detailed studies will be needed in the future to better quantify the complex flow patterns in the vicinity of Taylor Yard. The use of a physical model may be appropriate as part of these future studies.
5. The effects of the grading alternatives depend on when stored water is diverted and then released, relative to the timing of the peak flows and the flow regime in the channel.

4.2 RECOMMENDATIONS

The results presented in this report represent an initial analysis of the proposed conceptual alternatives. The details of the alternatives themselves, such as the precise depth of excavation or the elevation of channels linking the river to Taylor Yard, need to be optimized to provide maximum impact. Fine-tuning of the alternatives with the model involves significant uncertainty and would require considerable geometry and structure data. Calibration of the model is necessary for any additional study, especially considering the complexity of the flows due to the basin size, sensitivity to flood flow timing, the mixed flow regime, and backwater effects. A two-dimensional model would be needed for a detailed analysis of the local flow regime or any proposed structural components.

Lastly, it would be useful in a future phase of work to evaluate potential hydrologic and habitat benefits of applying 'Taylor Yard type' floodplain features along important contributing tributaries of the Los Angeles River (such as Tujunga Wash, Arroyo Seco, or Rio Hondo). Such a future study could build upon the analyses conducted for the primary Los Angeles River channel for the current study and would offer insight into dynamics of the greater watershed and how management decisions may offer comprehensive watershed benefits.

5. REFERENCES

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APPENDIX A
MIKE 11 Hydrodynamic Model

HYDRODYNAMIC MODULE OF MIKE 11

The hydrodynamic description is based upon the equations of conservation of mass and momentum (the Saint-Venant equations). Including the Chezy description for hydraulic resistance and lateral inflow results in the basic equations used in the model, described as follows:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad \text{continuity equation}$$

$$\frac{\partial}{\partial x}\left(\alpha \frac{Q^2}{A}\right) + \frac{\partial Q}{\partial t} + gA\frac{\partial h}{\partial x} + \frac{g|Q|Q}{C^2 AR} = 0 \qquad \text{momentum equation}$$

Q	- discharge (m^3/s)
x	- space coordinate (m)
t	- time
A	- flow area (m^2)
h	- water elevation (m)
α	- Momentum distribution coefficient (-)
R	- hydraulic or resistance radius (m)

The equations are solved as fully time-centered implicit difference scheme. Implicit finite difference equations are solved in a computational grid consisting of alternating Q and H points. Q points are located where the discharge is computed at each time, and H points are located where the water level is computed at each time. The model automatically generates the computing grid based on the user requirements.

The derivates in continuity and momentum equations are expressed at time level n+1/2, as follows:

The momentum equation is centered at the Q point.

$$\frac{\partial Q}{\partial t} \approx \frac{\left(Q_j^{n+1} - Q_j^n\right)}{\Delta t}$$

$$\frac{\partial h}{\partial x} \approx \frac{\frac{\left(h_{j+1}^{n+1} + h_{j+1}^n\right)}{2} - \frac{\left(h_{j-1}^{n+1} + h_{j-1}^n\right)}{2}}{\Delta 2x_j}$$

The continuity equation is centered at the H point.

$$\frac{\partial Q}{\partial x} \approx \frac{\frac{\left(Q_{j+2}^{n+1} + Q_{j+2}^{n}\right)}{2} - \frac{\left(Q_{j}^{n+1} + Q_{j}^{n}\right)}{2}}{\Delta 2x_j}$$

$$\frac{\partial h}{\partial t} \approx \frac{\left(h_{j+1}^{n+1} - h_{j+1}^{n}\right)}{\Delta t}$$